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A MANUAL

OF

NATURAL PHILOSOPHY,

COMPILED FROM VARIOUS SOURCES,

AND

DESIGNED FOR USE AS A TEXT-BOOK

IN HIGH SCHOOLS AND ACADEMIES.

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PREFACE.

THE compiler of the following pages deems no apology necessary for offering to the public another work on Natural Philosophy. Of the several works on this subject now before the public, and with the same general design as the present, each one, no doubt, possesses its own peculiar excellencies, and is adapted, more or less, to aid in advancing the great cause of education; but in the multitude of seminaries of learning, of different grades, in our country, considerable variety in the text-books used in them is absolutely necessary. Without claiming for the present work, therefore, superiority in every respect over others that have appeared before it, it is believed an appropriate place will be found for it, as an assistant in promoting the cause of general education.

As the work professes to be only a compilation, little or nothing that is new or original is, of course, to be expected in it; but, while the compiler has freely used the works of others, he has generally given his own illustrations, seldom adopting their language, and never, except when it happened to accord perfectly with his

own modes of thought and expression. This has been done, not from a desire of being unlike others, but with the hope of being able thus to condense more within the limits of the work, and to preserve a greater uniformity of style. During the preparation of the work, the peculiar wants of those for whom it is specially designed have been constantly kept in mind; and the writer is not without hope, from his long experience in teaching, it may not be found altogether unsuited for the use of those to whom it is more especially offered. At the same time it is believed it will be found adapted to the wants of such general readers as are seeking solid instruction, rather than momentary gratification.

In the writer's work on Chemistry, published several years since, the subjects of Heat, Galvanism, and Electro-Magnetism are treated of at length; and it was, therefore, considered entirely unnecessary to introduce them into the present, which is designed to accompany the former, the two together forming a connected treatise. It may, indeed, be objected that these topics belong rather to Natural Philosophy than to Chemistry; but they are, in fact, so intimately related to both of these branches, that, to the student, it matters little with which they are more particularly associated, while the public lecturer, because of the constant use of acids required in performing the experiments in Galvanism and Electro-Magnetism, will find it much the most convenient to discuss these subjects, at least, in connection with his course of lectures on Chemistry. And if we were com-

pelled to draw a line between these two branches of science, so as to make each as independent of the other as possible, we should be obliged to make the same division; since a course of study in Natural Philosophy will be quite complete, as far as it goes, without including the doctrines of Heat or Galvanism, both of which, however, lie at the very foundation of a Chemical course, and cannot be dispensed with from the most elementary treatise on the subject. It is believed, therefore, that the division adopted is not only theoretically correct, but that it will be found, in practice, more convenient than any other to the teacher, and more advantageous to the student.

In the articles on Electricity and Magnetism, and perhaps in a few other instances, persons making use of both works will observe a little repetition, but not so much as to occasion any inconvenience.

The following is a list of the works chiefly made use of in compiling the present volume, viz:—Elements of Natural Philosophy, by Dr. Golding Bird; the Treatises on Mechanics, Hydrostatics, Pneumatics, Optics, Optical Instruments, Polarization of Light, Electricity and Magnetism, in the Library of Useful Knowledge; the Treatises on Mechanics, Hydrostatics, Pneumatics, Sound, &c., in the Encyclopedia Metropolitana; Cours de Physique de l'Ecole Polytechnique, par G. Lamé; a Treatise on Hydrostatics and Pneumatics, by Dr. Lardner; a Treatise on Optics, by Sir David Brewster; a

Treatise on Mechanics, by Capt. Henry Kater and Dr. Lardner; The Philosophy of Sound and Musical Composition, by W. Mullinger Higgins; a Manual of Electricity, Magnetism and Meteorology, by Lardner and Walker; Experimental Researches in Electricity, by Sir M. Faraday; and Scientific Dialogues, by Rev. J. Joyce. Besides these, occasional reference has been made to a few other works, as the Encyclopedias, Scientific Journals, &c.

The writer would not omit the occasion to tender his acknowledgments to those of his friends who have favoured him by their counsel during the preparation of the work, and to express the hope that it may not be found unworthy of the interest they have manifested in its progress.

Middletown, Ct., Oct. 1, 1845.

CONTENTS.

CHAPTER I.

CHAPTER II.

CHAPTER III.

CHAPTER IV.

CHAPTER V.

CHAPTER VI.

CHAPTER VII.

CHAPTER VIII.

NATURAL PHILOSOPHY.

CHAPTER I.

MECHANICS.

1. *First Principles.* — Matter is the general name for everything or substance that has length, breadth and thickness, and which is capable of affecting the senses.

2. It is the object of Natural Philosophy to make us acquainted with the various qualities or properties of matter, and the manner in which different masses of it affect each other.

3. There are certain general properties which are common to all kinds of matter, as magnitude, figure or form, impenetrability, inertness, divisibility, attraction, &c. But before proceeding to the discussion of these, several mathematical terms, that will sometimes occur, must be explained.

4. A *point* is supposed to be without length, breadth, or thickness; a mere division between two lines.

A *line* is mere length without breadth or thickness; it is indeed a mere division between two surfaces, as two pieces of paper, the edges of which we may suppose in contact.

A *surface* is supposed to have length and breadth without thickness, and may be considered as dividing two solids which are in contact.

A *plane* is a surface on which, if a straight line be placed, it will touch at every point.

A *solid* is a body having length, breadth, and thickness.

An *angle* is the opening made by two straight lines which meet at some point.

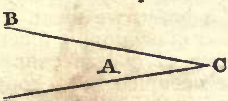

Fig. 1.

Thus, the opening A, figure 1, made by the two lines BC and CD, is called the angle A, or the angle BCD, which means the same.

Question 1. What is matter? 2. What is the object of Natural Philosophy? 3. What are some of the general properties of matter? 4. What is a *point*? A *line*? A *surface*? A *solid*? An *angle*? A *right angle*? An *acute angle*? An *obtuse angle*? How are angles measured?

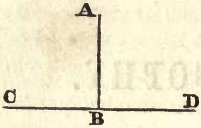

Fig. 2.

When one of the lines meets the other so as to make equal angles on each side of it, those angles are said to be *right* angles. The angles ABC and ABD, figure 2, are right angles.

Fig. 3.

An angle greater than a right angle, as ABC, figure 3, is called an *obtuse* angle; one less than a right angle, as the angle B C D, figure 1, is called an *acute* angle.

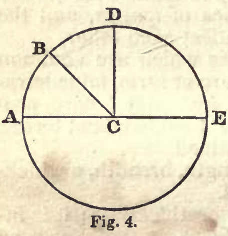

Fig. 4.

The magnitude of an angle is usually estimated by the part of the circumference of a circle included between its sides, supposing the point of meeting of the two lines to be at the centre. The whole circumference for this purpose is supposed to be divided into 360 parts, called degrees. Therefore A C B, figure 4, is an angle of 45 degrees (usually written 45°), and A C D an angle of 90°. So B C E is an angle of 135°.

5. Upon examining the various properties of bodies, we observe, that several of them are essential to and inseparable from every form of matter. Such are magnitude, form or figure, and impenetrability. We cannot even conceive of a particle of matter existing without these. They are therefore called the *essential* properties of matter.

6. Other properties are considered as *secondary* or *incidental*, as attraction, colour, divisibility, inertness, hardness, elasticity, flexibility, &c.

7. By the magnitude or extension of a body, we mean its length, breadth and thickness, or its power of occupying a certain portion of space, without which we of course cannot conceive it to exist. And as the space occupied by a body must be limited, every body or portion of matter must possess some form or figure, which is only the limits of extension.

Quest. 5, 6. What incidental properties of matter are mentioned? 7. What is meant by the *magnitude* of a body?

8. By the impenetrability of matter, we mean that one portion of it will not permit another portion to occupy the same space at the same time. There are three kinds or forms of matter, as we shall see more fully hereafter; viz., solids, as gold, iron, wood, &c.; liquids, as water, oil, mercury, &c.; and the gases, as the air, which constantly surrounds us, carbonic acid, &c.

Now solids, we know by daily observation, will not allow other bodies to occupy the same space with themselves, at the same time; and the same may be shown of liquids and gases. When a stone or other heavy solid is thrown into water, it sinks into it, but it first pushes away or removes the water in order to make room for itself. So, if we turn a glass tumbler bottom upward, and press it down perpendicularly into a vessel of water, the water does not rise and fill it, because of the air it contains. It does indeed rise a little in the tumbler, because the air is compressed together, but no force can make the water fill the glass entirely, unless the air is first allowed to escape.

9. By the inertness of matter is meant its inability to put itself in motion, or to stop itself when once put in motion. It is sometimes called *inertia*, and is simply resistance to a change of state, whether of rest or motion. Thus a body, as a cannon ball, being once at rest, would forever remain so unless acted on by some external force; so when once put in motion, as when it is fired from the cannon, were it not for the resistance it meets with from the atmosphere and other causes, it would continue to move forever with the same uniform velocity.

This of course cannot be demonstrated, though it is no doubt true. A body put in motion by man does indeed soon come to a state of rest, but the continuance of its motion depends greatly upon the resistance it meets with, the motion continuing longer in proportion as the resistance is less. Thus a body will move longer on smooth ice than on a floor, and longer through the air than on smooth ice. If all resistance, therefore, could be removed, we infer the motion of the body would be perpetual.

10. Every portion of matter with which we are acquainted is capable of being separated or divided into parts; but it is believed that every body is made up of an immense number of particles or atoms which are almost inconceivably minute, and entirely incapable of destruction or division. These parti-

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Quest. 8. What is meant by the impenetrability of matter? What three forms of matter are there? How is it shown that water and air are impenetrable? 9. What is meant by the *inertness* of matter? What is the reason that a body once put in motion does not continue to move forever? 10. Is every portion of matter capable of being separated or divided into parts? Are their ultimate particles or atoms incapable of division? Can these particles be made visible to the eye? What is said of the divisibility of gold? Into how long a thread has a pound of wool been spun? In what bodies do we have the most extreme division of matter?

cles are so very small, that no glass, however great its magnifying power, has yet been able to show them, nor is anything really known of their form or dimensions; but yet it is believed there is sufficient proof of their existence.

But matter, though composed of minute, unchangeable particles, is divisible to a surprising extent. An ounce of gold can be drawn into a wire several miles in length, and yet no flaw or evidence of separation between its atoms can by any means be discovered. So gold leaf may be beaten out with the hammer so thin that 360,000 of them will be required to equal an inch in thickness; and in the form of gilding for silver-wire it is often much thinner even than this. An exceedingly small portion of the substance called strychnia will diffuse itself through a whole pint of water, and render every drop bitter; and a single grain of hyposulphite of silver mixed with a little aqua ammonia, will sweeten 32,000 grains of water. A few years ago a woman in England spun a single pound of wool into a thread 168,000 yards, or nearly 100 miles in length.

But it is in the case of odoriferous bodies probably that we have the most extreme division of matter. A small piece of musk or camphor will fill a room with its particles, which are constantly thrown off and float in the atmosphere, for a great length of time without losing but a small part of its weight.

11. There are animalcules so small that a single drop of water may contain more than 26,000 of them; and 150,000,000 would have ample room in a tumbler of water to perform all their evolutions without interfering with each other. It is to be remembered too that each of these minute beings must have its various organs of circulation, respiration, locomotion, &c. How inconceivably small then must be the particles of which their bodies are composed!

12. The particles of which all bodies are composed possess another property called *attraction*, which causes them to adhere together with greater or less force. This is called the attraction of cohesion. We know nothing of its cause, but give the name to the force by which the particles of bodies are held together.

13. There are also other varieties of attraction, as the attraction of gravitation, capillary attraction, electrical attraction, magnetic attraction, and chemical attraction or affinity. Electrical and magnetic attraction will be treated of under electricity and magnetism respectively, but the discussion of affinity belongs exclusively to chemistry.

Quest. 11. How many animalcules may be contained in a single drop of water? Must each of these have the different organs of respiration, circulation, &c.? 12. What is meant by attraction? 13. What varieties of attraction are mentioned?

14. *Cohesion.* — All bodies being composed of particles of incalculable minuteness which are capable of being separated from each other, it follows that there must be some force by virtue of which solid bodies maintain their form, and their parts are preserved from being scattered like those of fluids merely by their own weight. This force is called *cohesion*, or sometimes the *attraction of cohesion*. It is the force by which the parts of all bodies are prevented from separating from each other, and falling to pieces; and when a body is broken it is this force which is overcome. It is exerted only when the particles are apparently in contact, or the distance between them is insensible. Thus, if two drops of mercury are brought near each other on a plate of glass, they remain separate until they approach so near each other that they appear to touch, when they immediately unite and form a single globule.

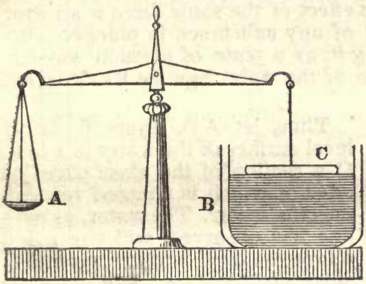

Fig. 5.

If a plate of metal or glass be suspended in a balance, and exactly counterpoised by weights, as in figure 5, a slight additional weight at A will cause the plate C to rise; but if now a basin of water B is put under it, so that it shall just touch the surface of the water, it will be found that a considerable additional weight will be required at the opposite end of the beam to detach the plate from the fluid surface, in consequence of its cohesive attraction. So two plates of glass finely polished and a little moistened, when pressed firmly together, adhere with considerable force. If two lead bullets are each scraped clean on one side and pressed together, one of them being turned or twisted a little at the same time, they may be made to unite so firmly that it will require a force equal to a number of pounds to separate them. Two freshly cut surfaces of caoutchouc or India rubber, when firmly pressed or hammered together, if perfectly dry and warm, will cohere almost as firmly as if they originally formed but one piece.

In liquids this force is feeble, though, as we have seen, it is not wanting. It is this which causes the drop of water to ad-

Quest. 14. What is cohesion? What force is overcome when a body is broken? At what distance only is it exerted? How is this shown by two drops of mercury on a plate? How is it shown by a metallic plate suspended from a balance on the surface of water? Will two plates of polished glass adhere with considerable force? How may two lead balls be made to adhere? Is there any cohesion among the particles of liquids? How is the presence of cohesion in liquids shown?

here to the lip of the vessel from which it is poured, and to trickle down the side instead of dropping perpendicularly downwards, as would be the case if no attraction existed between the solid of which the vessel is composed and the liquid. It is this force, indeed, which causes water to wet any other substance, as this effect could not be produced but for its existence.

15. Sometimes, when the bodies that adhere are of different kinds, as in the case of the metallic plate and the water above described, or in the case of the silvering upon the back of a looking-glass, the term *adhesion* is used, leaving the term cohesion to be applied only to those instances in which the particles are of the same kind; but the distinction is unimportant.

16. *Capillary Attraction.* — That force by which water or other liquids are made to rise in very small tubes is called *capillary attraction.* The effect of the same force is also seen whenever a plate or rod of any substance is plunged into a fluid capable of moistening it, as a plate of glass in water, by the rise of a small portion of the water against its sides, as if attracted by the glass.

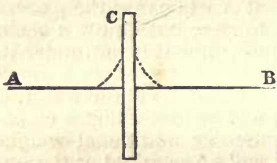

Fig. 6.

Thus, let A B, figure 6, be the level surface of the water in a basin, C a section of the glass plate, one edge of which is plunged vertically into the water. The water, as every one has observed, will rise a little above the level surface, against the sides of the glass plate, as represented by the dotted curved lines in the figure. The same effect is also seen in the similar rise of the water around the sides of a tumbler or other vessel containing it, and indeed in most liquids, when contained in vessels in ordinary use. In order that it may take place, it is only necessary that the liquid should be of such a nature as to be capable of moistening the substance of which the vessel is formed.

But these phenomena are best observed by using small glass tubes, and water coloured with ink, or other colouring matter. The smaller the bore of the tube is, the higher the water will rise.

Quest. 15. When has the term *adhesion* been used? 16. What is capillary attraction? How is it shown when a plate or rod is plunged into a liquid? Does the water always rise a little around the sides of vessels in which it is contained? In order that this rise may take place, what only is necessary? How are the phenomena of capillary attraction best observed? On what does the height to which the liquid will rise depend? Will a liquid always rise to the same height in tubes of the same bore? Will all liquids rise to

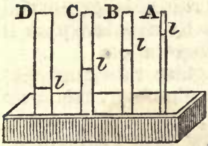

Fig. 7.

This is shown in figure 7, in which A B C D represent several tubes of different bore, open at both ends, and immersed in water, and *l l l l*, the heights to which the water rises in them severally. It attains the greatest height in small hair-like tubes; and hence the force which causes the rise is called *capillarity*, or *capillary attraction*, from the Latin word *capillus*, a hair.

The height to which water will rise in tubes of the same bore is always the same; but of other liquids, as oil of vitriol, alcohol, or solution of common salt, some will rise higher, and others not so high. When the bore of the tube is one-eighth of an inch, water will rise about a quarter of an inch.

This force is also exerted between two plates, when brought sufficiently near each other, and immersed in a fluid.

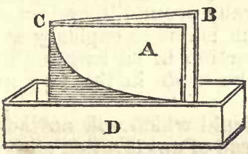

Fig. 8.

The experiment is best performed by taking two pieces of glass, A and B, figure 8, an inch and a half wide, and two inches long, and placing them in a trough of coloured water, D, with two of the edges in contact as at C, while the opposite edges are a little separated. The two plates will then make a small angle with each other, and the water will be observed to rise to a considerable height on the side C, where the plates touch each other, and gradually to fall towards the other side, forming the well-known curve called the hyperbola.

If a drop of water is placed in a small conical tube, by the force of capillarity it immediately begins to move towards the smallest end of the tube, whatever may be its position.

It is by this force of capillarity that water rises in a piece of sponge, or cloth, or other similar substance, as oil in the wicks of lamps, &c., which may be considered as a collection of a great many short capillary tubes, promiscuously thrown together. By the same force water is raised from the depth of several feet beneath the surface of the earth to keep the soil moist, from which it is constantly evaporating by the heat of the sun. Were it not for this provision of nature, the surface of the earth would often become so thoroughly dry and parched, during the long intervals that occur without rain, that all vegetation must necessarily be destroyed. But the water which

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the same height? Will this force be exerted between two plates? What is the effect when a drop of water is placed in a conical tube? How is the rise of water in a sponge or piece of cloth explained? How may such porous substances be considered? How may we account for the rise of the water in the soil from the depth of several feet? Is this an important provision of

accumulates beneath the surface during rains, is preserved there as in a reservoir, and gradually rises by capi larity as it is needed to supply the constant wants of vegetation.

To illustrate this point, take a piece of glass tube, open at both ends, and not less than half an inch in diameter, and from twelve to eighteen inches long, and support it as nearly as may be in a perpendicular position, in a shallow vessel capable of holding water. Then, after stopping the lower end loosely, fill the tube with perfectly dry sand or loam, and pour into the basin some water; it will be seen that the water will gradually rise in the tube, moistening the sand until it reaches quite to the top, though if the tube is eighteen or twenty inches long, it may require several days for the purpose.

Capillary attraction is in some instances made to exert great force. A weight suspended by a rope perfectly dry will be drawn up a considerable height, if the rope is moistened with water. The fibres of the rope pass spirally around it, and their swelling by absorbing the water, which is due to capillary attraction, necessarily occasions a contraction in its length. If the rope is sufficiently strong, it may be made in this way to lift several hundred pounds.

17. When a solid is immersed in a liquid which will not adhere to it so as to moisten it, then, instead of an elevation of the liquid, we see a depression. This is the case with mercury in a glass vessel, all around the sides of which a depression will always be observed. When, therefore, a capillary glass tube is plunged into a vessel of mercury, the fluid metal will not rise so high in it as the surface of that contained in the vessel.

It is on this principle that a small sewing-needle may sometimes be made to float upon the surface of water. To insure success in the experiment, the needle should first be oiled slightly and wiped clean, and then placed very carefully upon the surface of the water. The perspiration of the hand is of sufficiently oily a nature to prevent the water from adhering to the needle; or it may be rubbed upon the hair, and then wiped clean. If the surface of the needle is once moistened, it immediately sinks.

Some insects are enabled to walk upon the surface of water by means of this repulsion between their feet and legs and the water. The same repulsion is seen in drops or even large globules of dew that are often observed standing upon the leaves of plants, particularly the cabbage. When the leaf is

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nature? How may the rise of water in the soil be illustrated by means of a tube filled with sand? Is capillary attraction exerted with any considerable force?

Quest. 17. What is the effect when a solid is immersed in a liquid which is not capable of moistening it? How may a small sewing-needle be made to float upon water? How are some insects able to walk upon the surface of water? Why does a drop of water roll unbroken upon a cabbage-leaf?

moved, the water will often roll off quite unbroken, leaving the leaf of the plant dry.

18. A slight modification of the action of this same force is seen in the attractions and repulsions which take place between two balls, or other light substances, when thrown upon the surface of water or other liquids. When two balls, both of which are capable, or both incapable of being wet with water, are made to float upon the surface of this liquid, if they come within a certain distance of each other, they are observed to rush together, as though an attraction existed between them. Balls of wax or wood will answer for the purpose.

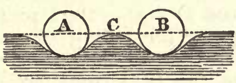

Fig. 9.

A and B, figure 9, are supposed to be two balls of the former substance floating upon water. As the water will not readily moisten the wax, a cavity is produced around the balls; and if they come within a certain distance of each other, the surface of the water at C will be depressed a little below the general level, and the pressure against the outside of each will then be greater than that against the inside. As a necessary consequence, they will rush together.

If both balls are capable of being moistened with the liquid, then the surface at C between them will tend to rise a little above the general level, and will thus draw the balls together. But if one of the two balls used is of such a nature that its surface may be moistened by the liquid used, while that of the other ball is incapable of it, then they will appear to repel each other.

Fig. 10.

The balls D and E, figure 10, are supposed to be of this character. One of the balls, D, raises the water all around it by the attraction of its surface, while the other repels it; so that, when brought together, the latter seems to slide off from the heap of water raised by the former.

The same attractions and repulsions are observed between the sides of a vessel containing a liquid, and substances floating in it.

19. Closely allied with capillarity are the phenomena of *endosmose* and *exosmose*. When two liquids of different densities are separated by a membrane, as a piece of bladder, or unoiled

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Quest. 18. When will two balls thrown upon the surface of water appear to attract each other? What substances may be used for the purpose? What will be the effect if one of the balls is moistened by the liquid used and the other is not? 19. What is the effect when two liquids of different densities are separated by a thin membrane, as a piece of moistened leather, or by a porous substance? In what direction does the liquid move through the membrane? What other properties are closely connected with cohesion?

leather, or by unglazed porcelain, two currents become established, one from within to without (exosmose), the other in the contrary direction (endosmose).

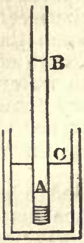

Fig. 11.

A good method to illustrate it is to take a glass tube half an inch or more in diameter, as B, figure 11, and tying a piece of bladder or unoiled leather over one end for a bottom, as seen in the figure at A, put in some sugar and stand it in a tumbler of water, C, at the same time pouring a little water into the tube upon the sugar. In the course of a few hours the water will be found to rise in the tube, having entered by endosmose through the leather at the bottom of the tube. If the tube is allowed to stand, the liquid will rise after a number of days to the height of several feet. If the sugar had been put into the tumbler outside of the tube, and pure water in the tube, exosmose would have taken place, and the tube have become empty. As a general rule, it is found that the least dense liquid has a tendency to pass to the most dense, and of course to dilute it. This is the case in the above instance, the solution of sugar being of course more dense than the water.

Closely connected with cohesion are several other properties which seem to be accidental, as *tenacity*, *brittleness*, *elasticity*, and *flexibility*.

20. The *tenacity* of bodies is dependent directly upon the intensity of the attractive force among the particles, by which they are prevented from being separated so far as to cause a rupture or fracture of the mass. This property varies greatly in different substances, the metals being in general most tenacious. But in the metals there is a great difference, a force of about twenty pounds being sufficient to draw asunder a wire of bismuth $\frac{1}{10}$th of an inch in diameter, while an iron wire of the same size would support a weight of more than five hundred and forty pounds. Next to iron, copper and platinum are most tenacious.

21. *Brittleness* is obviously the reverse of tenacity; bodies that are brittle are capable of supporting little weight. This property is often associated with hardness, and is frequently acquired by bodies in the process of *hardening*. Thus steel, when made very hard, is at the same time exceedingly brittle; cutting instruments are, therefore, usually made partly of iron to give them the necessary strength.

22. When a body is capable of being bent in any manner, within moderate limits, by the application of force, it is said to

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Quest. 20. On what is the *tenacity* of a body dependent? Does this property of bodies vary considerably? What metal is most tenacious? 21. What is said of *brittleness?* May a hard body be at the same time brittle? 22. When is a body said to be *flexible?* What is necessary in a body pos-

be *flexible;* for a body to possess this property it is necessary that the attraction existing between one portion of its atoms should be capable of being partially overcome, and allowing them to be separated farther from each other, while another portion of the atoms are pressed more closely together.

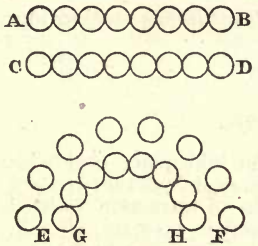

Fig. 12.

Thus, let A B and C D, figure 12, represent two rows of atoms of a cylindrical rod of metal or other substance capable of being bent in the form of a bow, by the application of a sufficient force in the proper direction. As the bending takes place, the length of one row is increased, while that of the other is diminished, as may be seen by comparing the curved rows E F and G H with A B and C D respectively. This of course can be accomplished only in the manner pointed out by the separation of the atoms of one row a little from each other, while those of the other row are pressed nearer together. Among the most flexible bodies are lead, gold, silver, annealed copper, soft iron, especially when heated to redness, several kinds of wood, wax, &c.

23 By the *elasticity* of a body is meant its capability of resuming spontaneously its original form upon the removal of the coercive force, when it has been bent as described above. Elastic bodies must therefore be so constituted as to allow a portion of their particles to be momentarily, at least, removed at greater distances from each other, without having their cohesion overcome, and others of them pressed into closer proximity with each other without becoming permanently fixed in that position. The attraction between the partially separated atoms on one hand, and the repulsion between the unnaturally approximated atoms on the other, will both tend to restore the body to its original form. Sometimes this change of form may be entirely imperceptible to the eye; and yet it is demonstrable that this change does take place. Thus, ivory is one of the most elastic solids that is known; and a ball of it, when thrown upon a marble floor, rebounds in consequence of this property, its form on striking the floor becoming altered and compressed, but it exhibits no signs of it to the eye.

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sessing this property? In what part of the body, as the bending takes place, are the particles pressed nearer together, and in what part are they separated? 23. What is meant by the elasticity of a body? How must an elastic body be constituted? What will tend to restore the body to its original form? Will this change of form always be perceptible to the eye? How is this demonstrated by the use of ivory balls? Do elastic bodies differ in regard

Different elastic bodies vary extremely in the extent to which they will yield without rupture; but most solids that are elastic suffer more or less change of form by being long compressed. The gases, as atmospheric air and carbonic acid, are the most elastic of all bodies; they never yield to any force, however long they may be compressed.

Among the most elastic solids are glass threads, steel springs, and unannealed copper and brass.

Liquids are but slightly elastic.

GRAVITATION.

24. Cohesion and capillary attraction take place only when the particles are at insensible distances, or in apparent contact; but all matter is endued with a species of attraction which is exerted at all distances, and is constantly in exercise. To this force we give the name *Gravitation.* Every one knows that when any substance, as a stone, is permitted to fall from the hand, it rapidly approaches the floor in a straight line. Now the stone is composed of inanimate matter, and of itself is absolutely inert, and incapable of changing its position or state (§ 9), consequently its falling must have been produced by some force acting upon it. This force is found to be the attraction of the earth. The measure or amount of this force in the case of any particular body constitutes the *weight* of that body.

25. This attraction is exerted at the smallest and the greatest distances, between the smallest masses of matter and the earth on which they lie at rest, and between the earth and sun and other vast bodies that constitute our solar system.

26. If a mass of lead or other heavy substance be suspended by a string, it will, when left free to move by the action of this force, be made to point directly to the earth; and this occurs in every place, whether in America, in Europe, or in India, proving that the attraction is everywhere towards the earth. By further examination it will be seen also that the mass always tends towards the centre of the earth, which may be considered the point from which the force emanates.

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to the extent to which they will yield without rupture? What are some of the most elastic solids? Are liquids elastic?

Quest. 24. What is gravitation? Is a stone let fall from the hand capable of putting itself in motion? Why then does it move towards the earth? What is the *weight* of a body? 25. At what distances is gravitation exerted? 26. To what point in the earth do bodies tend? If four bodies are suspended on opposite sides of the earth, what will be their position with reference to each other? What is a plumb-line?

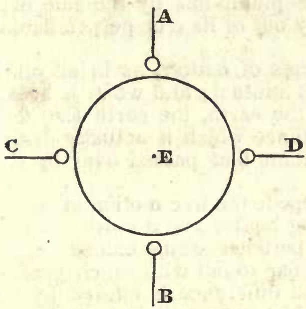

Fig. 13.

This may be illustrated by referring to figure 13, in which the circle E is supposed to represent a section of the earth through the centre, and A B C D the position of the heavy body suspended by a string in four different places diametrically opposite each other.

27. From this it will be seen that two plumb-lines, which are merely lines swinging freely with heavy weights attached to them, used by mechanics, can never be perfectly parallel with each other; and the farther they are from each other, the farther will they be from a parallelism.

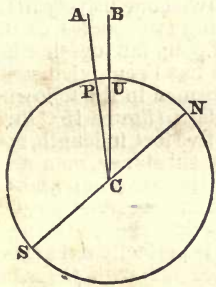

Fig. 14.

Let the circle S P U N, figure 14, be a section of the earth from north to south through the city of Philadelphia (Pa.); it will also pass very nearly through Utica in the State of New York, which is about three degrees and eight minutes north of the former place. Now suppose A and B are two plumb-lines, the former at Philadelphia, and the latter at Utica; they will tend to meet at the centre C, and of course must make the above angle of three degrees eight minutes with each other. But in the ordinary practice of the mechanic, as in carpentry, the error that would be occasioned by considering such lines parallel, may be entirely disregarded.

28. The amount of the attraction of any two bodies for each other will be proportional to their respective quantities of matter. Masses of matter, therefore, on the surface of the earth, have an attraction for, or gravitate towards, each other; but the attraction of the earth is at the same time so much greater, in consequence of its greater quantity of matter, that their attraction for each other is quite insensible. Still, bodies at the surface of the earth do exert an influence on each other;

Quest. 27. Will two plumb-lines near each other be parallel? If two plumb-lines are suspended, one at Philadelphia, and the other at Utica in the State of New York, which is nearly on the same meridian with Philadelphia, what angle would they make with each other? Would the error arising from considering plumb-lines parallel, ordinarily be sensible in practice? 28. To what will the amount of the attraction of two masses of matter for each other be proportional? Why is not the attraction of two masses of

and it has been found that the plumb-line by the side of a high mountain is drawn sensibly out of its true perpendicular position.

This attraction between masses of matter, as in all other cases where force is exerted, is mutual; and when a heavy body, as a stone, falls towards the earth, the earth also falls towards the stone; but the distance which it actually passes through will be as much less than that passed over by the stone, as its mass is greater.

29. If there were nothing to impede the free motion of bodies near the earth's surface, all falling bodies would move towards it with equal velocity. Daily experience seems indeed to contradict this, as heavy bodies appear to fall with much greater velocity than light ones; but the difference is caused by the resistance of the atmosphere, which retards light bodies more in proportion to their weight than it does heavy ones. That the observed difference in the velocity of light and heavy bodies falling towards the earth is to be attributed to the influence of the atmosphere, is shown conclusively in the well-known experiment of letting two bodies of this kind, as a feather and a piece of coin, fall together in a tall receiver from which the air has been exhausted.

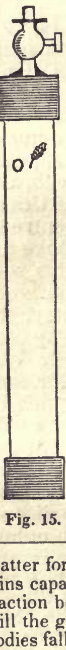
Fig. 15.

The experiment may be performed in the following manner. Let a receiver of glass (figure 15), three inches in diameter, and four or five feet in length, contain a feather and some heavy substance, as a piece of coin. After attaching it to the air-pump and exhausting the air, it is to be held in a vertical position and then suddenly inverted, so that the bodies may fall from end to end. If the air is perfectly exhausted, it will be seen that both bodies fall with the same velocity.

30. It might indeed seem, at first sight, that, independent of the retarding influence of the air, heavy bodies should fall more rapidly than those that are lighter; but it is to be recollected that matter of itself is entirely inert, and that consequently the force required to set a mass in motion, or give it any required velocity, will be exactly in the ratio of the quantity of matter. Thus, if a body weighing one pound falls by the force of gravity with a given velocity, to cause

matter for each other near the surface of the earth perceptible? Are mountains capable of drawing the plumb-line from its true position? Is the attraction between two masses always reciprocal? In approaching each other, will the greater or smaller mass move over the greater distance? 29. Do all bodies fall towards the earth with equal velocity? Why do heavy bodies, in falling, move more rapidly than light ones? How may it be shown that, but for the resistance of the air, both heavy and light bodies would fall with equal velocity? 30. Should it require more force to set a heavy body in motion

another body of four pounds' weight to fall with the same velocity will, of course, require the exertion of four times as much force. They should therefore fall with equal velocities.

31. The ascent of light bodies, as smoke and vapor, or a balloon, through the air, furnishes no exception to the universality of the action of gravity, but is in strict accordance with it. In air and in liquids, the particles of which are free to move among themselves, the bodies having the least weight in proportion with their bulk, will be forced upward by the greater gravitation of the heavier. Now this is the case in the instances mentioned, as will be more fully explained hereafter; the balloon, for instance, being lighter than the same volume of air, is forced upward by the tendency of the air to fall beneath it and occupy its place.

32. The spherical form of the earth and planets appears to result from this law; for all the parts of these bodies being equally attracted towards the centre of the mass, would arrange themselves at equal distances around it, or, in other words, the mass would take the spherical form.

33. Taking advantage of this property, lead-shot are cast perfectly spherical in form, by causing the globules of the melted metal to fall from the tops of high towers, so as to become solid before reaching the bottom. The attraction of the particles among themselves causes the mass while falling through the air to take the form mentioned. To prevent the shot from being bruised by the fall, they are received at the bottom in a cistern of water.

34. The attraction of bodies at different distances is inversely as the squares of those distances. This seems to be the law which regulates the action of all forces which emanate from a centre, and spread themselves around. If two bodies at the distance of a foot attract each other with a force equal to 1, then at the distance of two feet their attraction will be only $\frac{1}{4}$, and at three feet distance it will be $\frac{1}{9}$, &c.

The attraction of the earth, or the gravitation of bodies towards it, is greatest at the surface, and diminishes as we ascend

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than is required for a light one? Ought a body weighing one pound then to fall as rapidly as one weighing four pounds? 31. Does the ascent of light bodies, as smoke and vapour, furnish any exception to the laws of gravity as above described? How is the ascent of these bodies explained? 32. From what does the spherical form of the earth and planets result? 33. How are shot cast so as to be of a perfectly spherical form? How are shot prevented from being bruised by their fall? 34. How does this force vary with the distance? If two bodies at the distance of a foot attract each other with a force equal to one, what will be their attraction at the distance of two feet? At the distance of three feet? Where is the attraction of the earth greatest? Above the surface, how does the earth's attraction decrease? From what point is the distance to be reckoned? How much would a body weighing a pound at the surface weigh at the height of 4000 miles? How is this result obtained?

above or descend below it. Above the surface, the attraction diminishes according to the law just stated, the distance being reckoned from the earth's centre. Thus, if we call the semi-diameter of the earth 4000 miles, as it is very nearly, then at twice this distance, or 8000 miles from the centre, a body that would weigh a pound at the surface would weigh only $\frac{1}{4}$ of a pound; and at 12,000 miles from the centre, or 8000 miles from the surface, it would weigh only $\frac{1}{9}$ of a pound, &c.

35. Below the surface, the force of gravity diminishes only as the distance; that is, a body weighing a pound at the surface, at the distance of 1000 miles below, or one-fourth of the distance to the centre, would weigh only $\frac{3}{4}$ of a pound; and 2000 miles below the surface, it would weigh only $\frac{1}{2}$ a pound, and so on.

But it is to be noticed that in all these cases, even if we could find means to transport ourselves to the places supposed, we could not make use of the ordinary balance to determine the truth or falsity of our deductions; for the weights used losing of course just as much as the substance weighed, they would balance each other as perfectly at any of these positions as at the surface. At the distance of the moon, which is about 240,000 miles, or 60 semi-diameters of the earth from us, bodies would weigh only $\frac{1}{3600}$ as much as at the earth's surface; yet bodies that would counterpoise each other at the earth would of course do the same at the moon. The torsion balance, to be described hereafter, would however furnish the means of determining the question.

36. As the earth is not a perfect sphere, and all parts of its surface are not therefore at an equal distance from the centre, the force of gravity must vary at different places, being less at the equator than at the poles; but the variation is inconsiderable, though easily determined by means hereafter to be described.

37. *Centre of Gravity.*—The centre of gravity of a body is that point about which all its parts will be equally balanced in every position of the body. Consequently, if this point is supported by mechanical means, the body, whatever may be its form or position, will lie at rest.

The proper idea of the centre of gravity will readily be obtained by considering what takes place when an attempt is made to balance a straight wire, of some ten or twelve inches

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Quest. 35. How does the force of gravity diminish below the surface? If a body weighs a pound at the surface, how much will it weigh 1000 miles below the surface? If we could transport ourselves at pleasure to places above and below the surface, could we make use of the ordinary balance to verify these results? Why? What balance may be used for the purpose? 36. Are all parts of the earth's surface equally distant from the centre? Is the force of gravity of equal intensity at the equator and at the poles? 37. What is the centre of gravity of a body? How may a correct idea of the centre of

in length, on the back of a knife. Every particle of the wire is drawn downward equally by the earth's attraction, and the wire inclines to fall one way or the other until it is made to rest exactly upon its centre; then the attraction of the particles on one side of the knife, being precisely equal to that of those on the other side, an equipoise will be produced, and the wire will be supported. This point at which it is supported will be the centre of gravity of the wire.

In bodies of a regular form (as the circle, square, cube, and sphere) and uniform density, this point is always found exactly at the centre; but this is not the case if the form is irregular, or if some parts are more dense than others.

38. The centre of gravity of many bodies which are composed of the same kind of particles is found without difficulty. Thus, the centre of gravity of a triangle will be in the point where two lines, drawn from the vertices of two of its angles to the middle of the sides opposite, meet.

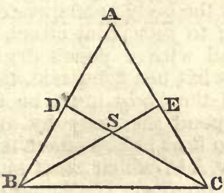

Fig. 16.

* In the triangle A B C, figure 16, according to what has been said, the centre of gravity must be somewhere in the line B E, drawn from the vertex B to E, the middle point of the side A C opposite; and it must also be somewhere in the line C D, drawn in like manner, from the vertex C; but as it must be in both of these lines at the same time, it must be at S, the only point that is common to the two.

39. In any figure bounded by straight lines, the centre of gravity may be found by dividing it first into triangles, and finding the centre of gravity of each, and then finding the centre of gravity of these triangles considered as separate masses.

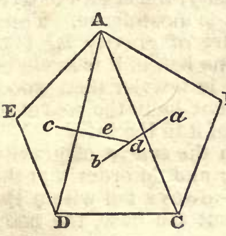

Fig. 17.

Thus, let A B C D E, figure 17, be the body in question; divide it into the three triangles A B C, A D C, and A D E, and find the centre of gravity of each as already described, which we will suppose to be the points *a b* and *c*. Then join two of these points, as *a* and *b*, by the line *a b*, in which of course will be the centre of gravity for these two triangles; and the exact position of this point will be as much nearer to *b* than to *a*, as the triangle A D C is

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gravity of a body be easily obtained? When will an equipoise of the wire be produced? In bodies of a regular form and uniform density, where is the centre of gravity? 38. How may the centre of gravity of a triangle be found? 39. How may the centre of gravity be found in any figure which is bounded by straight lines?

greater than A B C. We will suppose it to be at *d*. Then join this point and *c*, and in this line proceed to find, in the same manner as before, the point *e*, which will be the centre of gravity between the parts A D C B, and the triangle A D E, or, in other words, the centre of gravity of the whole body.

Though we have spoken of the centre of gravity of a body as being a point in the body itself, yet this is not necessarily the case. In a ring of uniform density, for instance, the centre of gravity will be at the centre of the circle, a point equally distant from any portion of the solid.

40. When a body is suspended by a cord attached to some point in it, its centre of gravity, when it is at rest, will always be in a line let fall perpendicularly from that point.

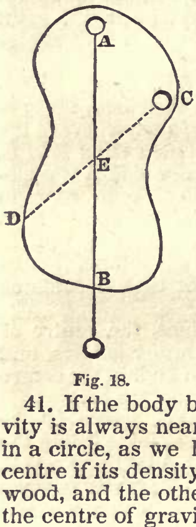

Fig. 18.

The centre of gravity of an irregular body, considered as a surface, as a piece of board, A B C D, figure 18, may therefore be found as follows. Let the body be suspended by some point, as C; to this point attach a plumb-line (§ 27), and with a pencil draw C D. According to what has been said, the centre of gravity of the body must be in this line. Then suspend the body by another point, A, and to it as before attach the plumb-line, and draw A B, which must also contain the centre of gravity. But being in both of these lines, it must of course be in their common intersection, E; and, upon trial, it will be found that the body will balance itself very accurately upon this point.

41. If the body be not of uniform density, the centre of gravity is always nearest to the part which is most dense. Thus, in a circle, as we have stated, the centre of gravity is at its centre if its density be uniform; but if one half of it is made of wood, and the other half of lead, which is heavier than wood, the centre of gravity of the whole will not be in the centre of the circle, but considerably to one side of it in the lead.

42. A line let fall perpendicularly from the centre of gravity of a body is called the *line of direction;* and, in order that the body may be supported, this line must always fall within the base on which it rests. If it falls without the base, the body will fall.

Quest. 40. When a body is suspended by a cord so as to swing freely, where will its centre of gravity be? How may the centre of gravity of an irregular surface be found? 41. If a body is not of uniform density, towards what part of it is its centre of gravity found? 42. What is the *line of direction* of a body? What must be the position of this line in order that a body may stand firm?

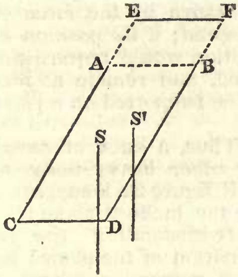

Fig. 19.

Thus, the body A B C D, figure 19, whose centre of gravity is at S, though inclined, remains firm, because the line of direction falls within the base C D; but if we place upon it another piece, A E F B, by which the centre of gravity of the whole body will be changed to S′, it will fall, because the line of direction will then fall without the base.

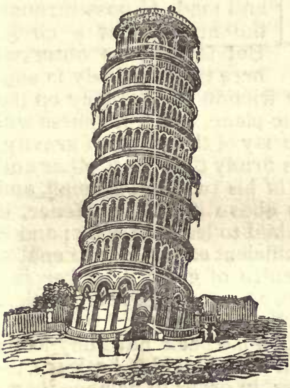
Fig. 20.

43. In Pisa in Italy is the well-known leaning tower, figure 20, which inclines 15 or 16 feet from a perpendicular; but it has stood firm in this position many hundred years, the line of direction, notwithstanding its inclination, still falling considerably within its base.

44. From what has been said, it will be seen the stability of a body will depend chiefly on two circumstances; its height, and the extent of its base. A pyramid stands firm, because its centre of gravity is comparatively low, and its base is very extensive, in proportion to its magnitude. On the other hand, a sphere is easily put in motion, because from its figure it rests upon a single point; and if the plane which supports it is ever so little inclined, the line of direction will fall at one side of this point, as is shown in figure 21.

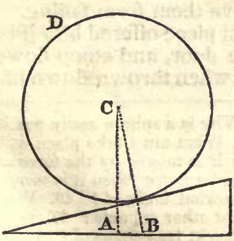

Fig. 21.

Let C be the centre of the sphere of which the circle B D is a section; C A will be the line of direction which falls out of the base or point of support, this being at B. Hence, the body will move down the plane.

Quest. 43. How much does the leaning tower in Pisa incline from a perpendicular? Has it been long in this position? 44. On what two circumstances does the stability of a body chiefly depend?

45. Whenever a body is made to move by the force of gravity, its centre of gravity must descend; if its position or form is such that any change of position would require this point to be raised, it will be supported, and remain at rest. Hence, a mass with a wide base may be supported on a plane considerably inclined.

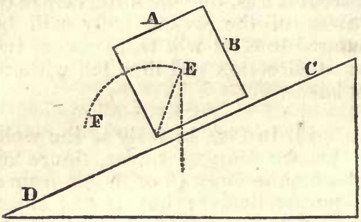

Fig. 22.

Thus, a cube of metal, or other heavy body, as A B, figure 22, is supported on the inclined plane C D, notwithstanding the inclination of the plane; for if it moves, its centre of gravity must still be raised and made to pass through the arc E F of a circle. But it is to be observed here that the body is supposed to roll and not slide. If the friction of the body on the plane is small, it may slide down the plane, which of course will be entirely independent of any property of the centre of gravity.

46. Man, when erect, stands less firmly than most other animals, because the base, composed of his two feet, is small, and his centre of gravity is very high above it. (§ 44.) Hence, it requires no little dexterity in the child to learn to walk; and it is a long time before he acquires sufficient experience to enable him at all times to preserve his centre of gravity, by keeping the line of direction within the base, as he balances himself first upon one foot and then upon the other.

47. A man carrying a burden upon his back naturally leans forward; and when carrying it on one shoulder he leans towards the other side. Rope-dancers, in order to balance themselves the more readily, hold in their hands a long pole, loaded at each end, which enables them the more easily to change their centre of gravity by moving the pole in one direction or another, as may be necessary to preserve them from falling.

48. Little James had a twenty-five cent piece offered him if he would place his back firmly against the door, and stoop down and pick the money up from the carpet, when thrown down im-

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Quest. Why does a pyramid stand firm? Why is a sphere easily put in motion when resting on an inclined plane? 45. What must take place with regard to the centre of gravity of a body, when it is moved by the force of gravity? How does the centre of gravity of a cube move when it is turned over, even though it may rest on a plane somewhat inclined? 46. Why does man, when erect, stand less firmly than most other animals? 47. Why does a man, when carrying a burden upon his back, lean forward? If his burden is upon one shoulder, why does he lean towards the other side? By what means do rope-dancers balance themselves upon the rope? 48. Why could not little James stoop down to pick up the piece of money on the floor before him, when standing in the position described?

mediately before him; but after many trials he found it impossible, and was obliged to give it up, wondering greatly what could be the reason. If he had studied this subject, he would have known that when a person stoops forward he is obliged to throw his body backward, so that his centre of gravity may be supported; but this being impossible in the present case, in consequence of his back being against the door, he could not stoop enough to reach the floor without pitching forward.

The same youth had a miniature horse which he was accustomed to stand on the edge of the table on his hind feet, as though he would make him pitch off upon the floor; but under the horse from his breast proceeded a stiff wire with a heavy weight at the end, so that the centre of gravity of the whole fell under the table. The particular manner in which the horse was supported allowed it to vibrate considerably backward and forward, as though he were rearing.

49. The shape of bodies may sometimes be so contrived as to make them appear to rise when they are actually falling. The case of the double cone rolling up an inclined plane is often referred to.

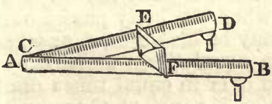

Fig. 23.

The body E F, figure 23, consisting of two equal cones united by their bases, is placed upon two straight and smooth rulers, A B and C D, which at one end meet at a small angle, and rest upon the table, but at the other are raised a little above the table. The double cone will roll towards the elevated end of the rulers, and will have the appearance of ascending; but, from its peculiar form, it is manifest upon examination that, on the contrary, it is falling. To make this plain, it will only be necessary to hold a ruler parallel to the table over the rolling body, and as it advances it will be seen to fall more and more from it.

50. So a circle of wood, or some other light substance, may be made to move a short distance up an inclined plane by making one side heavier than the other, and placing it properly on the plane.

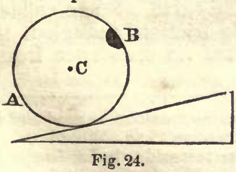

Fig. 24.

Let A B, figure 24, be a circle of wood situated on an inclined plane, having a piece of lead B attached to it near the circumference; it will roll up the plane, the whole wheel actually rising, until the weight B has nearly reached the lowest point, when it will stop. It might at first seem that the wheel has

Quest. 49. How may a solid in the shape of a double cone be made to roll up an inclined plane? Does the centre of gravity of the body ascend? 50. How may a circle of wood be made to rise, by its own gravity, a distance on an inclined plane?

really raised itself; but though its whole mass has risen, the centre of gravity, which we will suppose at C, has fallen. If now it is desired to roll the wheel farther up the plane, it is manifest that a greater effort will be required than if it had not been loaded; but after the weight B has passed the highest point, it will move on as before of its own accord.

MOTION AND FORCE.

51. By the motion of a body we mean its change of place, which, in consequence of its inertia, as we have seen (§ 9), can take place only by the application of some force. So also by force we understand the power which produces motion, or has a tendency to produce it.

52. Motion may be absolute through space, or one body may have a motion relatively to another, which may itself be at rest or in a state of motion. But we know nothing of any other than relative motion, and to this only therefore will our remarks be confined.

53. The degree of rapidity with which a body moves is its *velocity*, which may be *uniform*, as when the body passes over equal spaces in equal times; or it may be *accelerated*, as when the portions of space passed over in equal times increase; or *retarded*, as when the spaces passed over in equal times diminish. When this increase or diminution is constant, the velocity is said to be *uniformly accelerated* or *retarded.*

54. It has already been stated (§ 9), that a body once put in motion would continue to move for ever, unless stopped by some force; or, in other words, that it would never stop itself. But an experiment of this kind of course was never made; we every day see bodies in motion, some indeed moving with immense speed, but all alike soon come to a state of rest. This is because of the resistance they constantly meet with. This resistance arises from several causes, as the resistance of the air, the constant action of gravity, and *friction*. The resistance occasioned by friction is slight on bodies projected through the air, as a cannon ball; but it is very great on bodies moving over rough surfaces, as the surface of the earth. Some solids, as ice, occasion comparatively but little friction, though it is impossible to find a body which opposes no resistance from this cause.

Quest. 51. What is meant by *motion ?* By what must motion be produced ? 52. What is *absolute* motion ? What is *relative* motion ? 53. What is *velocity ?* When is motion said to be *uniform ?* When is it said to be *accelerated ?* When *retarded ?* When is motion said to be *uniformly accelerated* or *retarded ?* 54. Why does a body when put in motion by man always come in a short time to a state of rest ? What occasions the resistance ? Is the resistance of the air considerable ?

55. The resistance occasioned by friction, though sometimes producing great inconvenience, is often made use of for important purposes. It is by the friction of the driving-wheels of a locomotive on the rails that it is made to move on a rail-road, frequently drawing after it an immense load. These wheels are made to revolve by the engine; but this would not put the cars in motion, it is evident, were it not for their great friction upon the rails; hence the rails must always be kept free from ice and snow, which would destroy or greatly diminish the friction, and cause the driving-wheels merely to revolve upon the rails, without putting the train in motion. Sometimes this is seen when the wheels of a locomotive are started suddenly, especially if it is attached to a heavily loaded train; for a moment the wheels slide upon the rails as they revolve, but the train soon starts and moves onward.

Friction is also made use of to check the motion of a train of cars upon a rail-road, or to stop it. This is done by means of a *brake*, which consists of a combination of levers by which heavy pieces of iron are made to press firmly against the rims of several of the wheels, thus gradually checking their motion. It is necessary that it should be done gradually, as the sudden stopping of the train when in rapid motion would be productive of injury.

56. The resistance occasioned by friction is seen when a person jumps from a carriage in rapid motion. When his feet strike the ground he is in danger of being thrown down, because the friction upon the surface is so great as to bring them at once to a state of rest, while his body tends to move onward as before. If the carriage were moving on smooth ice, by carefully jumping upon it the danger would be less, as it would allow his feet to glide over it a distance before coming to a state of rest.

57. The resistance of the atmosphere is much the greatest when the motion is rapid; when one moves his hand slowly through the air, its presence is scarcely felt; but if he moves it rapidly, the resistance is plainly perceived. The experiment will appear more decisive to the young learner by holding an expanded fan in his hand when waving it in the air. The resistance of the air to cannon-balls, which are projected through it with immense velocity, is very great.

Quest. 55. Is the resistance of friction sometimes made use of for important purposes? How are locomotives made to move on a railway? Why must the rails in winter be kept free from ice? How is the motion of the locomotive and the cars checked when necessary? 56. Why is a person liable to be thrown down on alighting from a carriage in rapid motion? What would be the effect if the carriage were moving over smooth ice, and the person should jump carefully upon the surface? 57. When is the resistance of the air greatest? What is the effect of moving a fan rapidly through the air? What is said of the resistance of the air upon cannon-balls when projected with great velocity?

58. The effect of gravitation is to bring a body in motion to the earth, which by its friction soon causes it to come to a state of rest, however rapid may have been its motion.

59. In any given case, the velocity with which a body will move, other things being equal, will depend upon the force with which it is impelled, and will be in the direction in which the force has acted. Two bodies of different weights will require forces inversely proportional to their weights to give them the same velocity (§ 30); and of two bodies having the same weight, one will move with twice the velocity of the other, if it be propelled with double the force.

60. Every force must always act equally in opposite directions. If a person press against the table with his hand, the table opposes a precisely equal resistance to his hand. A horse drawing a load forward is pulled backward by the load with an equal force. A bird flying in the air strikes it with its wings, and the reaction of the air is sufficient to sustain the weight of its body. In firing a rifle, the explosion of the powder, which gives the ball its velocity, also causes the recoil of the piece; and if it were no heavier than the ball, and were not held in its place, it would take the same velocity as the ball, but would move in the opposite direction.

If two boats of similar weight and form were on a smooth lake, and a man in one should pull upon a rope held by a person in the other, both would have to make the same exertion, and both boats would move with equal velocity; but if one of the boats had been anchored, and therefore remained at rest, the man in it holding the rope would have been obliged to make the same exertion.

61. This principle of motion or force is sometimes expressed by saying that action and reaction are always equal, and in opposite directions.

62. Motion is sometimes reflected; that is, a moving body strikes another that is fixed, and is thrown back or rebounds in an opposite direction. If an elastic body, as a ball, strike a plain surface perpendicularly, it rebounds perpendicularly; that is, it is thrown back in the same path it first took; but if it

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Quest. 58. How does gravitation act upon bodies in motion? 59. Upon what will the velocity of a body depend? When will two bodies of different weights move with the same velocity? 60. Must a force always act equally in opposite directions? When a person presses with his hand upon a table, what opposing force is there? How is a bird supported in the air? Why does a cannon or rifle recoil when fired? If the piece were no heavier than the ball, and unconfined, what would be the effect? How is this principle illustrated by two boats on a smooth lake pulled together by persons in them by a rope? 61. How is this principle of motion or force sometimes expressed? 62. When is motion said to be *reflected?* What is the *angle of meridian* and the *angle of reflection?* How do these angles compare with each other in magnitude?

strikes the plane obliquely, it rebounds with an equal obliquity, but in an opposite direction.

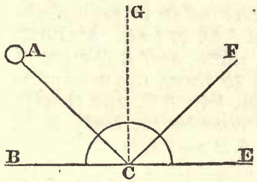

Fig. 25.

The law is as follows: Let B E, figure 25, be a plane surface, against which an elastic ball, A, is supposed to move in the direction A C, striking it at C; it will then rebound in the direction of C F with the same velocity as before. If now at the point C we make C G perpendicular to B E, it will be found that the angle A C G, called *the angle of incidence*, is exactly equal to the angle G C F, called the *angle of reflection*.

63. A single force acting upon a body can give it motion only in a straight line (§ 59); two forces are necessary to produce curvilinear motion.

If two forces act upon a body at the same time, the body will move in a diagonal between them.

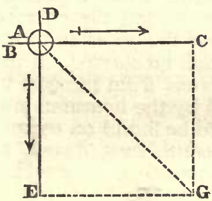

Fig. 26.

Thus, let A, figure 26, be a body acted on at the same instant by two equal forces at right angles to each other, one of which would cause it to move to C in the time the other would cause it to move to E; instead of taking either of these courses, it will move through the dotted line to G. To show more particularly that this would be the case, let us suppose that from B to C is east, and from D to E is south; the effect of the force B alone then would be to drive the body east a given distance, as from A to C in a second; and the effect of the force D alone to drive it the same distance south, as from A to E, in that time. Now, it is evident that neither of these forces would in any degree counteract the effect of the other; and if both act at the same time, the body must move with the same velocity both east and south; that is, it must move through the diagonal A G, which is called the *resultant* of the two forces. Evidently it is the diagonal of a square. The body at the end of the second will be in the same place as if the forces had acted successively, causing the body to move first to C or E, and then to G.

When the two forces are unequal, the direction the moving body will take may be readily determined.

Quest. 63. How will a body move when propelled by a single force? How will a body move when acted upon at the same time by two forces? What is the line in which the body moves called? How may the resultant be found when the two forces are unequal?

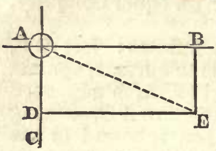

Fig. 27

Let A, figure 27, be a body acted upon by two forces in the direction of A B and A C. Suppose that the force acting in the direction of A B is equal to three, and that in the direction of A C, to two. Make the line A B equal to three, and A D equal to two, and parallel to these draw the lines D E and B E; then join A E, and this line will be the path taken by the body A. It is therefore the resultant of the forces A B and A D.

64. If the forces act at some other angle than a right angle, their resultant may be found in a similar manner. If there are more than two forces acting upon the body, the resultant of two of them may be first found, and then the resultant of this as a separate force, and a third force, and so on with all the forces.

These cases are not merely theoretical; they are every day actually occurring. As an instance of two forces acting at right angles, suppose a boatman rowing his canoe across a stream. He attempts to put his boat directly across, but the current sets him downward; and before he reaches the opposite bank, he finds he is far below the point from which he started. If the stream ran south, and he attempted to cross from the east to the west side, supposing the force exerted by the boatman precisely equal to that of the current, it would be found on examination he had proceeded exactly in a south-west direction. This would be the exact resultant of the two forces by which the boat would be moved. In order that the boat might proceed directly across the river from east to west, it would be necessary for the boatman to propel his boat constantly in the direction of north-west.

A steam-vessel, whose paddles tend to propel her northward, whilst the wind blows her to the eastward, and the tide is running in a third direction, is an instance of the action of these forces. The vessel cannot of course obey all the forces simultaneously, and takes a course which is their true resultant.

65. The combination of several motions sometimes produces results that at first appear a little singular. A person riding rapidly in the open air feels the drops of rain strike him in the face, although the drops may be falling perpendicularly; and

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Quest. 64. May the resultant be found in a similar manner when the forces do not act at right angles to each other? How may the resultant be found when there are more than two forces acting together? Do instances actually occur in which two or more forces act together? If a man should attempt to cross a river, the current of which ran south, in what direction would he move by propelling his boat directly from east to west? In what direction must he shape his course in order to pass directly across the river? 65. Why does a person riding rapidly in the rain feel the drops strike him in the face when they are falling perpendicularly? How will the drops appear to him to be

the drops will appear to him as though they came, not perpendicularly downward, but considerably inclined towards him. A person attempting to throw a ball to another passing rapidly in a rail-road car, would throw it, not directly at him, but at a point on the road considerably in advance of the car at the time; and though thrown directly towards the line of the track on which the car is moving, to the person in the car it will appear to come from a point considerably in advance of him, and at an angle considerably inclined from a perpendicular to the line of the road.

A heavy body let fall from the mast-head of a ship in full sail will appear to fall precisely as it would if the ship was at rest, and will strike the deck at the same distance from the mast; for, having the same motion as the ship at the beginning of its descent, it will appear, all the time it is falling, at the same distance from the mast, though the line of its descent is in reality a curve.

66. *Curvilinear Motion.* — Curvilinear motion is always the result of two or more forces, generally but two. These are called the *centripetal* and the *centrifugal* forces. By the former, the body is drawn towards the centre; by the latter, it tends to fly from the centre in a straight line, which is a tangent to the circumference of the curve in which the body moves.

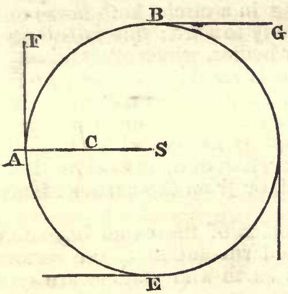

Fig. 28.

67. If a ball of some heavy substance is fixed to a cord, and made to revolve rapidly by holding the other end of the cord in the hand, while it is revolving, its tendency to fly off is plainly felt in its pulling, so to speak, upon the cord; and if now the cord should be broken, it will fly off in a straight line. In this case the cord may represent the centripetal force, and the force by which the ball tends to break the cord, the centrifugal force. In figure 28, let A be some heavy body revolving around the centre, S, in the circumference ABE; if, while it is in rapid motion, just as it arrives at the point A, the cord C is suddenly

falling? Suppose a person standing by the side of a rail-road wishes to throw a ball to another person passing in a car on the road: how would he throw it? Will a heavy body falling from the mast-head of a ship when sailing strike the deck at the same distance from the mast as it would if the ship was not in motion? How is this fact explained? 66. How many forces are necessary to produce *curvilinear motion?* Which way does the *centripetal* force tend to move the body? 67. If a heavy body is whirled rapidly round by means of a cord, what will represent the centripetal, and what the centrifugal force? If the cord should be cut as the body is revolving, in what

cut with a sharp knife, it will at once fly off by its centrifugal force in the straight line, A F, which is called a tangent (§ 69) to the circle. If the cord was cut when it was at the point B, it would take the direction B G, which is also a tangent at the point B. So if the cord was cut when the revolving body was at any other point, the body would fly off in a straight line, which would be a tangent to the circle at that point.

Boys take advantage of this force in throwing stones with a sling. The sling is so constructed that the stone is first made to revolve rapidly, so as to give it a great centrifugal force, and then is suddenly let go, by which a great velocity is communicated to it.

Drops of water flying from a wheel that is turning rapidly furnish another instance of the operation of the same force. Grindstones, and even strong iron wheels, have been broken in pieces in this manner, simply by causing them to revolve so rapidly that the centrifugal force of their outer parts becomes so great as to tear them asunder.

The same principle explains the well-known fact that a bucket of water may be swung over the head, so as to turn the top downward, without spilling the water; the centrifugal force of the water, when whirled rapidly, becomes sufficient to overcome entirely its gravitation.

68. When an equestrian is riding in a circle, both horse and rider are seen to incline considerably inward; this is to counteract the centrifugal force of their bodies, which often becomes very great, especially if the circle is small, and their motion rapid. But carriages not having this power to make compensation for the disturbing force thus called into existence, are often overturned when an attempt is made, as in turning a corner, to change suddenly the direction of their motion. They will of course always fall outward, or *from* the corner around which they are turning.

69. We have magnificent examples of the exact balancing of these two forces in the continued revolution of the various bodies of the solar system. The earth and planets are constantly moving around the sun as a centre; some of these also at the same time serving as centres around which other smaller bodies revolve, called satellites, or moons. At every point in

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direction will it move? How do boys, in throwing stones with a sling, take advantage of the centrifugal force? Why does water fly off from the rim of a wheel when it is made to revolve rapidly? Is there any danger in making grindstones revolve with great velocity? When a bucket of water is swung over the head, why does not the water fall out as the bucket passes bottom upward over the head? 68. Why does a horse, when running in a circle, incline inward? Why is a carriage in rapid motion in danger of being overturned in passing a corner? 69. Where may be found magnificent examples of the exact balancing of the centripetal and centrifugal forces? Around what central body do the earth and planets revolve? Around what body does the moon revolve? Why do not their bodies fly off into space?

their orbits, these bodies tend to rush off into infinite space in straight lines, as above described (§ 67), but are constantly held in by the attraction of the central body.

70. The *form* of the earth itself presents a remarkable instance of the effects of the centrifugal force produced by its rotation on its own axis. The motion of the earth's surface at the equator by its rotation on its axis, is about thirteen and a half miles a minute, by which a tendency is produced in the parts about it to fly off into space, like drops of water from a revolving wheel; but this result is prevented by the strong attraction of the mass of the earth acting from the centre, which constitutes the centripetal force of the parts. Still the effect of the centrifugal force is seen in the enlargement of the earth at the equator, the equatorial diameter being several miles greater than the polar diameter.

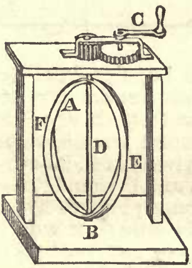

Fig. 29.

This alteration of the figure of the earth is easily illustrated by the apparatus represented in figure 29. On a perpendicular axis, A D B, are two thin brass hoops, which are fixed to the axis at A, but are loose at B. Now, when these hoops are made to turn rapidly by means of the handle, C, they become flattened in the direction of A B by the part at B rising, and enlarged in the opposite direction E F. This is occasioned by the centrifugal force of the parts at E and F.

LAW OF FALLING BODIES.

71. The fall of bodies to the earth when unsupported, is, as we have seen (§ 24), an effect of the earth's attraction, or gravitation. This motion of bodies, as every one has noticed, is not uniform; it increases rapidly as the body descends. If a lead bullet is dropped from the hand, it may be caught again if the effort is made instantly, as its motion is at first slow; but its velocity soon increases so as to carry it beyond the reach; and if the hand could be extended to it after it has fallen a few seconds, it would be dangerous to seize it, as, in consequence of the ball's great velocity, the hand would probably be injured. The fall of bodies, making no allowance for the resistance of the air (§ 57), is an instance of uniformly accelerated motion (§ 53).

Quest. 70. Is the *form* of the earth affected by its revolution on its axis? What distance does the surface of the earth move at the equator in a minute by its rotation over its axis? Is the equatorial or the polar diameter greatest? How is this modification of the form of the earth by its rotation on its axis illustrated by experiment? Why does the form of the brass hoops change when made to revolve rapidly? 71. Why do bodies, when unsupported, fall towards the earth? Is the motion of a falling body uniform? What kind of motion is the fall of a heavy body an instance of?

72. To prepare for the discussion of this subject, let us suppose that four men, with clubs in their hands, are standing in a row on smooth ice, and at such a distance from each other that if the first strikes a ball lying on the ice before him, after it has been moving a second, the second man may give it a blow precisely equal to the first, and in the same direction; and at the end of another second, the third may strike it a third blow just equal also to the first, and in the same direction; and at the end of the third second, the fourth man may strike it in like manner. We will suppose that the ball suffers no resistance from the air or from friction on the ice; and therefore, when an impulse is given it, it moves on with uniform velocity, and that the blow given it by each man would cause it to move sixteen feet in a second. The first man standing at A, figure 30, would give it an impulse that would carry it sixteen feet to

Fig. 30.

B, the first second; if it should receive no impulse from the second man B, it would move on just sixteen feet the next second; but, receiving an additional impulse from B equal to that received from A, it will, during the second second, move twice sixteen or thirty-two feet to C. On arriving at C, its velocity already acquired from the impulses of A and B would cause it to move thirty-two feet during the third second; but, receiving a third impulse from C equal to each of the others, it would, during this second, move three times sixteen or forty-eight feet to D. So, during the fourth second, by receiving the impulse of D, it would move four times sixteen or sixty-four feet to E.

73. Now, the circumstances attending the fall of bodies are similar to the above, but with this essential difference, that the force which puts them in motion, instead of acting by successive impulses, acts constantly. Let us proceed to inquire what difference this will produce in the results.

As the force which acts the first instant to put the body in motion continues to act at each successive instant with the same uniform intensity, and of course communicates at each instant the same velocity, it is evident that if, at the end of any given portion of time, as a second, this force (gravitation) should cease to act, the velocity already acquired would alone carry it during the next second through *twice* the space it moved through during the first second. But as the force really acts during the

Quest. 72. How are the four men on the ice supposed to be arranged? How far is the ball supposed to move the first second by the impulse given it by the first man? How far will it move the next second? How far the third, and how far the fourth second? 73. Does gravity act by successive impulses? As gravitation acts constantly, communicating at each instant the same velocity, if, at the end of any given time, as a second, it should cease, how much farther would the body fall the next second merely by its

second second, as well as the first, it will add the same amount to its motion as it gave it during the first second; altogether, then, during the second second, it will fall through three times the space it did during the first. During the two seconds from the beginning of the motion, the body will fall through four times the distance it fell the first second.

74. So, the velocity acquired at the end of the second second will (if gravitation should cease to act) carry it twice as far during the next two seconds as it passed the first two; that is, its acquired velocity will cause it to traverse during the third and fourth second twice the space it traversed during the first two seconds, or eight times the distance it traversed the first second alone. Half of this distance, or four times the space passed the first second, of course it will pass through the third second by its acquired velocity; but, to find the whole distance it will really traverse the third second, we must consider gravity as acting and communicating the same amount to its motion as during the first second. The whole space passed over during the third second will therefore be just five times that passed over during the first. In the same manner it might be shown that during the fourth second the body will fall seven times as far as it did the first, and during the fifth second nine times as far, and so on, the spaces passed each second from the beginning of the motion being as the odd numbers 1, 3, 5, 7, 9, 11, &c.

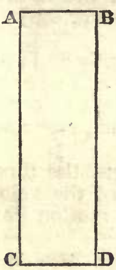

Fig. 31.

75. This may be illustrated, to some advantage, in the following manner. When a body moves uniformly, we determine the distance it traverses in a given time, as five seconds, by multiplying the time by its velocity. Thus, if a body moves twenty feet a second, it will in five seconds traverse five times twenty or one hundred feet.

Now if, in figure 31, we let the line A B represent the velocity of the body (twenty feet per second), and the line A C the time of its motion (five seconds), the surface of the figure A C D B, which is equal to A B multiplied by A C, will represent the space passed over (one hundred feet), in the five seconds. There is, indeed, no resemblance between space passed over by a moving body (which

acquired velocity, than it fell the first second? But as gravitation would really act during this second, as well as the first, how much motion would this add to that acquired during the first second? Altogether, then, how far should the body fall during the second second? How far would it fall during the first two seconds? 74. How far will the body fall by its acquired velocity during the third second? How far will it fall during the third second by its velocity previously acquired, and by the action of gravity taken together? How far will it fall the fourth second? How far the fifth, and how far the sixth second? 75. When a body moves uniformly, how do we determine the distance it will traverse in a given time? How do we determine

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is a *line*) and a *surface;* but as the surface of a rectangle, as A C D B, is found by multiplying together any two of its adjacent sides; and as the space passed over by a moving body, by multiplying the time of its motion by its velocity; it is evident that the space passed over by a moving body sustains the same numerical relation to the time of its motion and its velocity, as the surface of a rectangle sustains to any two of its adjacent sides. For numerical calculations, therefore, these three latter things respectively may be taken to represent the three former.

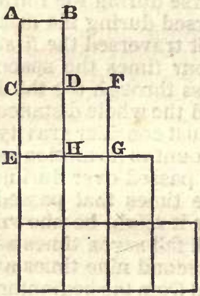

Fig. 32.

76. In the above case (§ 72) of the four men upon the ice, let A B, figure 32, represent the velocity communicated to the ball by the first man, and A C the time (one second) of its motion before receiving its second impulse; then will the surface A C D B represent the space (twenty feet) traversed in this time. The acquired velocity would now of itself cause it to move through a space equal to that already traversed, which may be represented by the surface C E H D; but, letting D F represent the velocity communicated by the second man, the distance it will move during the second second will be represented by the whole surface C E G F. So, it will readily be seen, the remaining parts of the figure will, in like manner, represent the spaces passed over during the third and fourth seconds.

77. But gravitation, as we have seen, acts constantly and not by successive impulses; and a falling body at the end of any given time, as a second, will have acquired sufficient velocity to carry it the next second, if gravity ceased to act, twice as far as it fell the first second. (§ 73.)

Now, if we let the line A *a*, figure 33, represent the time of falling (one second) of a falling body, and *a b* the velocity acquired at the end of this time, then, as the motion has

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the surface of a rectangle when its two adjacent sides are known? How does it appear that the surface of a rectangle sustains the same numerical relation to its two adjacent sides as the space passed over by a body moving uniformly sustains to its velocity and the time of its motion? 76. In the case of the ball moving on smooth ice by four successive impulses, what part of figure 32 represents the space it would move during the first second by the first impulse? What part represents the space it would pass the next second by its acquired motion? What part represents the whole space it would pass during this second? 77. What part of figure 33 represents the space a body will fall by the force of gravity the first second? What part represents the space it would pass the next second by its acquired velocity only? What part represents the space gravity alone would cause it to pass during this second? What part represents the space it would pass the second second by its velocity previously acquired, and by the continued action of gravity together? What part represents the space it would pass the third second?

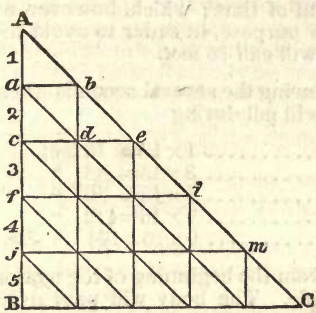

Fig. 33.

been uniformly accelerated, will the triangle A *a b* represent the space passed over during the second. If, now, gravity should cease to act, the velocity would be uniform; and, during the next second, the space traversed may be represented by the square *a c d b*, which it will be seen is just equal to twice the triangle A *a b;* but, in reality, during this second, gravity, by its continued action, would communicate the same motion as it did during the first, and the body would traverse the space represented by the figure *a c e b*, which is equal to three times the triangle A *a b*.

In the same manner it might be shown that, during the next or third second, it would traverse a space represented by the surface *c f i e*, which is five times the triangle A *a b;* and during the fourth second a space represented by the surface *f j m i*, which is seven times A *a b*, &c.

78. If we wish to determine the distance the body will fall in any given time from the beginning of the motion, we find that during the first second it moves through a certain space represented by the triangle A *a b;* during the first two seconds it moves through a space represented by the triangle A *c e*, which is four times A *a b;* during three seconds, through a space represented by the triangle A *f i*, which is equal to nine times A *a b*, &c. The spaces passed over in different times from the beginning of motion, therefore, are as the squares of the times; that is, in two seconds it will fall twice two, or four times as far as it fell the first second; in three seconds, three times three, or nine times the distance it fell the first, and so on.

79. The law of falling bodies, as above developed, may be fully demonstrated experimentally by means of *Atwood's machine*, so called from the name of its ingenious inventor; but it is too complex to be here described.

80. Now it has been found by numerous and accurate observations that bodies falling freely by the force of gravity pass

Quest. 78. What part of the same figure represents the space the body will fall during the first two seconds? During the first three seconds? During four seconds? What is the ratio of the spaces passed over from the beginning of the motion as compared with the times? What is the square of a number? 79. What is the design of Atwood's machine? 80. How far is it found by experiment a body falling freely will move the first second? How far will it move the next second? How far the third, and how far the fourth second?

through $16\frac{1}{12}$ feet the first second of time; which, however, as it is sufficiently accurate for our purpose, in order to avoid the inconvenience of fractions, we will call 16 feet.

The spaces passed through during the several seconds, then, will be as follows. The body will fall during

The 1st second	....	$1\times16=$ 16 feet.
" 2d "	....	$3\times16=$ 48 "
" 3d "	....	$5\times16=$ 80 "
" 4th "	....	$7\times16=112$ "
" 5th "	....	$9\times16=144$ " &c.

81. The spaces passed over from the beginning of the motion will be as in the following table. The body will pass over, during

The 1st second	....	$(1^2=\ 1)\times16=$ 16 feet.
" 1st two seconds	....	$(2^2=\ 4)\times16=$ 64 "
" " three "	....	$(3^2=\ 9)\times16=144$ "
" " four "	....	$(4^2=16)\times16=256$ " &c.

That is, the spaces passed over, as stated above (§ 78), are as the squares of the times; if the body passes over 16 feet the first second, it passes over 2^2 or 4 times 16 feet during the first two seconds, and 3^2 or 9 times 16 feet in three seconds. Hence, to find the distance a heavy body will fall in a given time, we have the following rule, viz. *Multiply the distance it will fall in one second* ($16\frac{1}{12}$ ft.), *by the square of the time in seconds.*

Suppose it was required to determine how far a heavy body would fall in 8 seconds. By the above rule, $8\times8=64$, and $64\times16\frac{1}{12}=1029\frac{1}{3}$ feet.

82. An easy method of determining the depth of a well, or the height of a tower, naturally suggests itself here. Suppose a person standing at the mouth of a well, the depth of which to the surface of the water he wishes to ascertain. Having a watch with a second-hand, he finds that a lead bullet let fall strikes the water in just $2\frac{1}{2}$ seconds. Thus, by the rule given above, $2\frac{1}{2}\times2\frac{1}{2}=6\frac{1}{4}$, and $6\frac{1}{4}\times16\frac{1}{12}=100$ feet, $\frac{25}{48}$which is the depth required.

It is evident that some little time would be required for the sound of the bullet in striking the water to reach the ear; but it would be so trifling that it may be entirely neglected.

Quest. 81. How far will the body fall the first two seconds? How far in three seconds? What is the rule for finding the distance a heavy body will fall in any given number of seconds? 82. How may we readily determine the depth of a well by letting fall a heavy body into it?

83. If a body is projected downward with a given velocity, the effect of gravitation is to be calculated as above, and to this the distance it would traverse by the projectile force is to be added. Thus, if a body be projected downward with a velocity of 50 feet a second, at the end of three seconds it will have fallen by the force of gravity 3^2 or $9 \times 16 = 144$ feet; and to this we are to add 150 feet, the distance it is projected, making in all 294 feet.

It is required to determine how far a body will fall in 7 seconds, which is projected downward with a velocity of 75 feet per second.

Answer. It would fall by the action of gravity $788\frac{1}{12}$ feet, and by the force with which it is projected 525 feet, making together $1313\frac{1}{12}$ feet.

84. If the body is projected perpendicularly upward, the distance it will rise by the force of projection is to be first calculated; and from this the distance it would fall in the same time by gravitation is to be subtracted. In the above example (§ 83), if we suppose the body to have been projected perpendicularly upward, and suppose that for the time gravitation should cease to act, it would have risen by the projectile force $50 \times 3 = 150$ feet; but, as gravitation acts constantly, the distance it would fall in the given time by this force, or 144 feet, must be subtracted from the 150 to find the height to which it would really ascend, which would be only 6 feet.

85. It is impossible, under any circumstances, to remove a body from the influence of gravity. When at rest, the body by this force presses upon the substance which supports it; if the support is removed, it falls with a uniformly accelerated velocity, as we have seen; if it is projected perpendicularly upward or downward, the action of gravity is to be taken into account, to find its real motion, and subtracted or added, as the case may be; and if it be projected in any other direction, this force equally exerts its influence. If a body be projected horizontally over a horizontal plane, it will strike the surface in the same time it would if allowed to fall freely by the force of gravity alone. The only effect of the projection has been to cause it to strike at a distance from the place to which, but for this, it would have fallen in a straight line. This principle is of great

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Quest. 83. If a body is projected perpendicularly downward, how is the distance it will move in a given time to be determined? If a body is projected downward with a velocity of fifty feet per second, how far will it move in three seconds? 84. When a body is projected perpendicularly upward, how will it be affected by gravity? How is the distance it will move in a given time to be determined? If a body were projected upward with a velocity of fifty feet per second, how far would it move in three seconds? 85. Is it possible by any means to remove a body from the influence of gravity? When a body is at rest, how is it influenced by this force? Will a body projected horizontally over a horizontal plane strike the plane in the same time as if it

importance in the firing of cannon; and it will be seen from what has been said that it is absolutely impossible to fire a ball in a straight line except perpendicularly, either upward or downward. As soon as it has left the mouth of the cannon it must begin to fall, if projected horizontally; or, if projected in a more elevated direction, it is prevented from rising as far as it otherwise would, and describes a curve called a *parabola*.

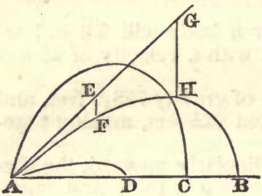

Fig. 34.

Thus, if a ball be fired in the direction A G, figure 34, it will not pass on in the line A E G, but will at once begin to fall below it. Let us suppose the force of the powder sufficient, but for the influence of gravity, to throw the ball from A to E in one second; as soon as it left the gun it would begin to fall by the force of gravity acting upon it, and at the end of the second it would be at F instead of E, and the distance E F would be found just $16\frac{1}{12}$ feet (§ 80), the distance which a body falls by the force of gravity in a second of time. So, at the end of two seconds, the ball would be found at H instead of G, where the projectile force alone would have carried it; and the distance G H would be equal to $64\frac{1}{3}$ feet, the space a heavy body falls through in two seconds. The body, therefore, would describe the curved line A H B.

It is found by experiment that the ball goes farthest when the piece is elevated about 45°, or half-way between a horizontal and a perpendicular line. If the piece is elevated more than this, the ball rises higher, but strikes the ground nearer, as at C; or, if it is elevated less than 45°, it comes to the ground sooner, as at D, though its path is less curved.

86. If a body, instead of falling perpendicularly, is made to roll freely down an inclined plane, the same laws of acceleration of motion prevail with regard to the motion along the plane, but the velocity will be less rapid in proportion as the height of the plane is less than its length. Thus, the motion of a body gliding freely down the inclined plane, A B, figure 35, will be uniformly accelerated, but its velocity will be to the velocity of a body falling vertically, as the height of the plane is to its length, that is, as A C is to A B.

Fig. 35.

In what has been said of the motion of bodies, it is of course

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fell perpendicularly? Does the ball fired horizontally from a cannon proceed in a straight line? What is the curve called which the ball describes? In what direction must the piece be pointed in order that the ball may proceed the greatest distance? 86. Is the motion of a body rolling freely down an inclined plane uniformly accelerated? Will it have attained the same velocity on reaching the foot of the plane as if it had fallen vertically through the

to be understood that no allowance has been made for the resistance of the atmosphere (§ 57), which in some cases is very great, and very much modifies the final result. The resistance of the atmosphere to a ball of three pounds weight, moving with a velocity of 1700 feet a second, is computed to be equal to 154 pounds.

87. It is to be observed also, that the laws of falling bodies, above developed, apply only to bodies falling within moderate distances of the earth's surface. We have considered the force of gravity as absolutely uniform, which is not true in fact, except within comparatively small distances of the surface. We have seen (§ 34), that above the earth's surface the force of gravity diminishes as the square of the distance from the centre increases; and consequently 4000 miles above the earth it is only one-fourth as great as at the surface. If, then, we should attempt to calculate, by our rule, the time a body would fall through this distance to the earth, we should not obtain an accurate result, because in this distance the force of gravity is constantly varying. A more complex rule is required in this and similar cases, which it would be out of place here to investigate.

88. As the attraction of the earth diminishes rapidly at great distances, there is a limit beyond which the velocity of a falling body cannot increase, however great the distance from which it may fall. It has been determined by mathematicians that a body falling to the earth from the sun or from one of the stars, if it were possible, would not attain on arriving at the earth a velocity of quite seven miles a second; and more than half of this velocity would be communicated to the body while passing through the last 1400 miles.

89. As the attraction between two bodies must always be mutual and equal (§ 60), it is evident that when the earth attracts a body, it must itself also be attracted; and if the body moves towards the earth, the earth must also move towards the other body. As, however, any mass which in its fall can come under the observation of man must be infinitely small when compared with the earth, so the distance through which the earth would be moved would be infinitely smaller compared with the distance the body would fall.

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height of the plane? Will the time of its falling be increased or diminished? Is any allowance here made for the resistance of the air? What does the resistance of the air amount to on a ball of three pounds weight moving 1700 feet a second? 87. Do these laws of falling bodies apply to bodies falling at great distances from the earth's surface? How much is the earth's attraction diminished 4000 miles from the surface? 88. What is the greatest velocity a body can attain in falling from the greatest distances to the earth? 89. Is the earth attracted by falling bodies? Why is not its motion perceptible?

90. The mean distance of the moon from the earth's centre is, as we have seen (§ 35), about 60 times the semi-diameter of the earth. This is found by dividing 240000 miles, which is the mean distance of the moon, by 4000, which is very nearly the earth's semi-diameter or radius. Consequently, the earth's attraction at the moon will be only $\frac{1}{3600}$th as great as it is at the surface; and a body during the first second or minute will fall only $\frac{1}{3600}$th as far as it would in the same time if let fall near the earth.

91. Now, by the rule above given (§ 81), it is easily determined that a body falling unobstructed near the earth would in one minute pass through 57900 feet, and $\frac{1}{3600}$th of this is $16\frac{1}{12}$ feet. That is, a body at the distance of the moon would fall towards the earth just the same distance in a minute, as it would fall if near its surface in a second.

92. As the moon revolves round the earth in an orbit very nearly circular, it is of course acted on by two forces, the centripetal and the centrifugal (§ 66); by the former of which it is constantly drawn towards the earth, while by the latter it tends to fly off into space. If either of these was destroyed, it would of course obey the other exclusively.

93. Now, it is not difficult to show that the moon does *virtually* fall towards the earth $16\frac{1}{12}$ feet every minute; or, in other words, that, if its centrifugal force were destroyed, it would at once fall towards the earth with a velocity that would cause it to pass over this distance the first minute of time. That is, the moon, if left to the influence of its centripetal force alone, would approach the earth in one minute through precisely the same space that a heavy body would fall by the law of gravitation if placed at that distance from the earth. From this it of course follows that the moon's centripetal force is nothing but the earth's attraction acting upon it as it would upon any other mass of matter placed at the same distance.

Let E, figure 36, be the earth, and M N L the moon's orbit. The moon revolves around the earth in 27 days, 7 hours, and 43 minutes, or 39343 minutes, and in one minute passes over $\frac{1}{39343}$ part of its orbit, or about 33 seconds of a degree. Let M N be this arc. By the centrifugal force alone, it would, in one minute, describe the straight line M O (§ 67), while, by the

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Quest. 90. How many times the earth's semi-diameter is the moon distant from the earth? How is this found? How great is the earth's attraction at the distance of the moon? 91. How far will a body fall in a minute near the earth? How far in a minute at the distance of the moon? 92. If the moon's centrifugal force were destroyed, what would be the effect upon her? 93. Does the moon *virtually* fall towards the earth $16\frac{1}{12}$ feet every minute? What follows from this? What is the explanation of figure 36?

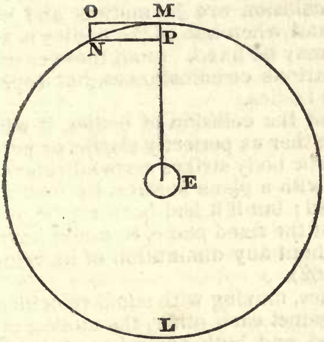

Fig. 36.

centripetal force alone, it would move from M to P. But the line M P is called the *versed sine* of the arc M N, which in this case is 33″; and the versed sine of an arc of 33″, in a circle whose radius is 240000 miles, is found to be $16\frac{1}{12}$ feet very nearly.

94. This is substantially the celebrated calculation of Newton in confirmation of the law of universal gravitation, which was first suggested by him. As he drew near the close of it, and perceived the result would be as he anticipated, conscious of its momentous importance, it is said he was so affected that he was unable to proceed, and was obliged to call in an assistant to complete it. (See *Brewster's Life of Newton*, Harper's Family Library, vol. xxvi. p. 144.)

COLLISION OF BODIES.

95. The force with which a moving body strikes another at rest is called its *momentum*, and is found by multiplying its weight by its velocity. When the weight of two bodies is equal, their momenta will be in proportion to their velocities; and if the velocity of two bodies is equal, their momenta, or quantity of motion, will be in proportion to their weights. The momentum of a body is found, therefore, by multiplying its weight by its velocity. If the weight is 5, and its velocity 20, its momentum will be $20 \times 5 = 100$.

A light body, therefore, by having its velocity increased, may be made to strike an obstacle with as much force as a heavier one which moves more slowly. A cannon-ball, of 3 pounds weight, moving with a velocity of 900 feet a second, will possess the same momentum, and strike a body at rest with the same force as another of 90 pounds weight, moving at the rate of 30 feet only per second; for $900 \times 3 = 2700$, and $90 \times 30 = 2700$.

96. The term *percussion*, or *collision*, is sometimes used to indicate the force with which a moving body strikes another;

Quest. 94. What is said to have been the effect upon Newton when first making this calculation? 95. What is the *momentum* of a body? How is the momentum of a body found? How may a light body be made to strike an obstacle with the same force as another which is much heavier? 96. What is meant by the *percussion* or *collision* of bodies? Upon what particular circumstance will the result of the collision of two bodies depend?

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the meaning is the same as *momentum*. Sometimes both of the bodies supposed to come in collision are in motion, and at others one of them is at rest; and when one of the bodies is at rest, it may be movable or it may be fixed. In all these cases the result will depend upon various circumstances, but especially upon the elasticity of the bodies.

97. In examining the effects of the collision of bodies, it will be sufficient to consider them either as perfectly elastic, or perfectly inelastic. When an inelastic body strikes perpendicularly against an immovable object with a plane surface, its motion is instantly completely destroyed; but if it had been elastic, on striking perpendicularly against the fixed plane, it would have rebounded perpendicularly without any diminution of its velocity, as we have seen above (§ 62).

98. If two equal inelastic bodies, moving with equal velocities in opposite directions, strike against each other, the motion of both will be instantly destroyed, and both come to a state of rest; but, if two equal elastic bodies, moving in like manner, strike against each other, they will both rebound with the same velocity they possessed before coming in contact.

99. The rebounding of elastic bodies is occasioned (§ 23) by the particles at first yielding at the point of contact, and then instantly returning, with the same force by which they were compressed, to their original position. If the particles of a body are perfectly fixed and unyielding, or if when compressed they retain perfectly the position to which they have been forced, it will be inelastic.

100. If we suppose an inelastic body, A, at rest, to be struck by another, B, of equal weight, both will move forward together after the collision, but with only half the velocity which B had before the collision. Half the motion of B would be communicated to A, and both together would have the same momentum B had at first. If B had been twice as heavy as A, it would have lost by collision with A only one-third of its motion, and both would have moved on together with two-thirds of the velocity of B.

If both bodies be supposed to be equal, and moving in the same direction, but B with twice the velocity of A, B will of course overtake A, and will communicate one-quarter of its ve-

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Quest. 97. In examining the results of the collision of bodies, how may we regard them? When an inelastic body strikes against an immovable object with a plane surface, what is the result? What is the result when a perfectly elastic body strikes perpendicularly against an immoveable solid plane? 98. What is the effect when two equal inelastic bodies, moving with equal velocities in opposite directions, come in collision? What would be the effect if the bodies were elastic? 99. What occasions the rebounding of elastic bodies? What is the condition of the particles of inelastic bodies? 100. If an inelastic body, B, strike another, A, at rest, equal in weight to itself, how would the two move? If B were twice as heavy as A, how would

locity to A, which will therefore have its own motion increased by one-half; and both bodies will move on together with three-fourths of the original velocity of B, or once and a half that of A. Thus, in every case of collision between inelastic bodies, if one is at rest, or both moving in the same direction, the sum of their momenta will be the same both before and after collision. But if they are moving in opposite directions, the body having the least momentum will have its motion destroyed, while the other will continue its motion with a momentum equal to the excess of its original momentum over that of the first.

101. But if an elastic body, B, is made to strike another, A, of equal weight with itself, the motion of B will be wholly communicated to A, which will move on with the same velocity before possessed by B. If both bodies are in motion in the same direction, but B with double the velocity of A, when B overtakes A, they will not move on together, as would be the case with inelastic bodies (§ 100); but B will communicate to A one-half of its velocity, by which A's velocity will of course be doubled. Both bodies will therefore move onward in the same direction as before, but they will have exchanged velocities, A's velocity being now double that of B's.

It will be seen, therefore, than when collision takes place between elastic bodies, the velocity lost by the striking body, and that gained by the body struck, will be twice as great as if the bodies were inelastic.

102. These principles may be very satisfactorily illustrated by means of balls suspended by small cords.

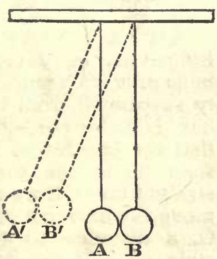

Fig. 37.

Thus, let A and B, figure 37, be two small balls of soft putty, which is perfectly inelastic, suspended by cords; on raising B a short distance to the right, and letting it fall against A, keeping the cord all the time fully extended, both balls will be found to move together to the left, as to A′ B′; but they will move to the left of their first position only about half as far as B was raised from this position to the right. The ball, B, first falls by the force of gravity, which, however, carries it only to the point

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the bodies move after collision? In all cases of the collision of inelastic bodies, provided they are not moving in opposite directions, how will the sum of their momenta before and after collision compare? If they are moving in opposite directions, what will be the result? 101. If an elastic body strikes another equal to itself at rest, what is the result? When collision takes place between elastic bodies, how much greater is the velocity lost by the striking body and that gained by the body struck than if the bodies were inelastic? 102. How may the collision of inelastic bodies be illustrated experimentally by means of balls of soft putty?

where the cord by which it is suspended becomes perpendicular, and it strikes against A; beyond this point the action of gravity is to retard it, as well as A, which will now be put in motion by B. We see, therefore, the reason why they should move together after collision only half as far as B moved before collision.

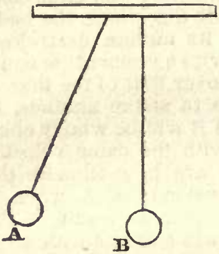

Fig. 38.

103. To illustrate the effect of the collision of elastic bodies, let A and B, figure 38, be two balls of ivory, which is a very elastic substance, suspended by cords, so as to move freely. When they have come to a state of rest, let B be drawn aside a little to the right, so as on falling to strike against A; the result will be that B, on striking A, will communicate to it all its motion (§ 101), and A will move on the same distance to the left of its position or rest, as B was carried to the right. On A's return it will strike in a similar manner against B, which will now move to the right, while A will remain at rest until B again returns, when the same effect will be produced as before. Thus the motion would continue perpetually, but for the resistance of the air, friction of the cord, &c., which will eventually bring both balls to a state of rest.

104. When several elastic balls are suspended so as to rest in contact with each other, the motion of the first will be communicated through those at rest, and the extreme balls only will move.

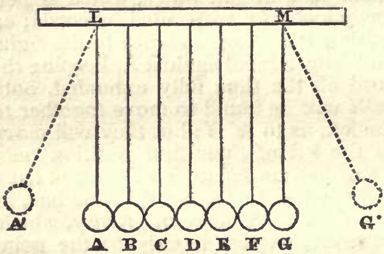

Fig. 39.

Let ABCDEFG, figure 39, be several balls of ivory accurately suspended from the bar LM by cords, so that the centres of all shall be in the same straight line. If we remove the extreme one, G, a distance to the right, as to G′, and then let it fall, it will strike against F with a momentum proportional to its velocity, but without perceptibly moving it or any of the intermediate balls; but A at the other extreme will start up to

Quest. 103. What will be the effect if balls of some elastic substance, as ivory, are used? 104. What will be the effect if a number of ivory balls are used suspended side by side, so as to be in contact, and one of the ex-

A′, a height nearly equal to that to which G had been raised. This ball then falling back, will strike against B, and motion will again be communicated to G, which will move as before; and thus a vibrating motion will be continued in the extreme balls, until, by friction and other resistance, they are at length brought to a state of rest. This curious action of the balls is occasioned by their almost perfect elasticity, by which the motion is communicated from particle to particle of each ball, almost without any motion of the mass of the ball. But as they are not in fact perfectly elastic, all the balls, usually after a little time, acquire a slight vibratory motion. This last effect is seen best when only three balls are used.

If, in the above experiment, two balls are drawn aside and let fall, then the two opposite ones will be thrown off; and so of any other number within moderate limits.

THE PENDULUM.

105. The *pendulum* consists of a single weight suspended by a cord or rod, so as to swing freely. If a rod is used, it must be flexible at the upper part, or so suspended as to allow it to move freely backward and forward.

When a weight so suspended is drawn aside a little from its position of rest, and then let fall, by the action of gravity (§ 70) it is immediately carried to its first position again; but when it arrives there, it has acquired considerable momentum, which, if there was no resistance from the air or other cause, would be sufficient to carry it as far to the opposite side of the perpendicular. It would then return again by the force of gravity to the perpendicular, and, by its acquired momentum, to the position from which it started, to again commence its motion precisely as before, and so on for ever. But, in reality, a body made to vibrate in this manner soon comes to a state of rest, in consequence of the resistance of the air and the slight friction occasioned at the point of suspension.

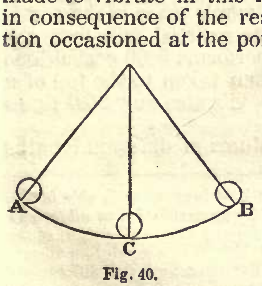

Fig. 40.

Let C, figure 40, be a ball of some heavy substance suspended by a thread. If it be now raised by the hand to B and let fall, it will immediately return with a uniformly accelerated motion to C, since the law governing the descent of bodies in curved lines is the same as if they descend perpendicularly or down an inclined plane (§ 86). As the body passes beyond C by its momentum,

treme ones is drawn a little aside and let fall against the ball next to it? Why do all the balls, after a little time, usually acquire a slight vibratory motion? If two balls are drawn aside and let fall against the others, what is the result? 105. What is a ***pendulum***? What force causes the motion

the force of gravity will act against its motion with precisely the same intensity as it had before acted in favour of it (§ 85); and, making no allowance for the resistance of the air or friction, the body should of course move to A, making A C precisely equal to C B. From A it will return by the force of gravity to C, and the momentum thus generated will carry it onward to B. Having arrived at B, it will again immediately return to C and A as before.

106. The motion of a pendulum, from its extreme point B on one side, to the opposite side A, is termed an *oscillation* or *vibration;* and it is a most important circumstance that, for pendulums of the same length, all the oscillations are performed in equal or very nearly equal times. If the arcs through which the weight swings are very small, though not perfectly equal, the oscillations are performed in precisely the same time; but if the arcs are larger, it is found the times required are a little longer.

107. The duration of an oscillation does not, therefore, depend in the least upon the nature of the substance of which the pendulum is made, nor upon the size of the weight used.

108. As the movements of the pendulum depend upon gravity, this instrument affords an excellent mode of determining the intensity of this force at different places on the earth's surface. A pendulum that vibrates 3600 times an hour at the equator, it is found would vibrate 3613 times an hour at the poles, which shows the force of gravity to be considerably greater at the latter place. This is occasioned by the enlargement of the earth at the equator, and flattening at the poles, as already illustrated (§ 70), by which the surface at the poles is brought nearer to the centre than the surface at the equator. The intensity of gravity at the poles is greater than at the equator, because the distance to the centre of the earth is less, the point from which gravity may be supposed to act (§ 26). The action of gravity is, indeed, the action of the whole mass of the earth, but the effect is the same as if it was exerted only from the central point. So a pendulum that performs 3600 oscilaltions per hour at the surface of the sea, when taken to the top of a neighbouring mountain $3\frac{3}{10}$ miles high, vibrates only 3597 times an hour.

109. The times required for pendulums of different lengths

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of the pendulum? Why should the distance it swings on each side of the perpendicular be equal? 106. What is meant by an *oscillation* or *vibration?* 107. Do the times required for the oscillation depend upon the weight of the pendulum, or the substance it is composed of? 108. Will a pendulum vibrate as rapidly at the equator as at the poles? What occasions the difference? Why may the attraction of the earth be considered as acting only from the centre? Will the pendulum vibrate most rapidly at the surface of the sea or at the top of a mountain? 109. What is the length of a pendulum that vibrates once a second at New York? What is the length when it vibrates half seconds?

to vibrate are as the square roots of their length. Thus, at New York, the pendulum which vibrates seconds is found to be 39.1 inches in length, while that which vibrates half seconds is only 9.7 inches long. Thus, as $1 : \frac{1}{2} :: \sqrt{39.1} : \sqrt{9.7}$. It may easily be determined that a pendulum to perform its oscillations in 2 seconds, must be 13 feet in length.

110. A clock is merely a machine propelled usually by a weight, for the purpose of continuing the motion of a pendulum and registering the number of its oscillations. This last office is performed by the pointers, of which there are usually three; one for seconds, one for minutes, and one for hours. Generally the pendulum of a clock is made of the proper length to perform its oscillations either in a half second or in a second (§ 109), and the wheel-work is adapted accordingly. When a seconds pendulum is used, it makes of course 60 oscillations in a minute, 3600 in an hour, and 86400 in 24 hours. A person looking at a clock in the afternoon observes that it is 24 minutes and 35 seconds past 3, which is in reality only saying that since 12 o'clock, the point of time at which the reckoning it is supposed was commenced, the pendulum has made 12275 oscillations or beats.

111. The motion of a clock is regulated entirely by the length of the pendulum; and usually the weight at its lower extremity is sustained by a screw, by which it may be raised or lowered a little at pleasure.

But we have seen (§ 106), that the pendulum, if left to itself, by reason of the resistance of the air and the friction at its point of suspension, will, after a time, come to a state of rest. To counteract this tendency, the machinery of the clock is so constructed, that, at each oscillation, it shall receive a slight impulse from the propelling power, by which means its motion is continued for any length of time without variation.

112. Any change in the length of the pendulum of a clock, therefore, will seriously affect its going. Now this change is produced by change of temperature, the length being increased in warm weather, and diminished in cold weather; so that the same clock is usually found to go faster in winter than in summer. An obvious remedy is to move the weight at its extremity a little up or down as occasion may require. But to do this accurately would be extremely inconvenient, not to say impossible, in practice; and several contrivances have been adopted to overcome the difficulty, the most important of

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Quest. 110. What is a clock? How does a clock show the number of oscillations the pendulum has made? When a person says it is 24 minutes and 35 seconds past 3 in the afternoon, what may he be understood to mean? 111. How is the motion of a clock regulated? How is the pendulum of a clock kept in motion? 112. Why do clocks generally go faster in winter than in summer? What is the object of the gridiron pendulum?

which is the gridiron pendulum. This is so constructed of rods of different metals, that the expansion or contraction of the rods of one metal in one direction, shall be counteracted by an equal expansion or contraction of the other in the opposite direction. The two metals used may be steel and copper, the latter of which is expanded or contracted by a given change of temperature much more than the former.

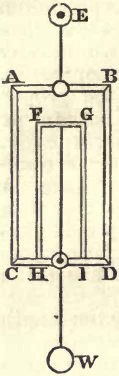

Fig. 41.

In figure 41, A B C D is a parallelogram of steel fixed to the rod E, while the bars F H and G I are of copper, and inserted firmly in the steel bar C D. The weight, W, is then attached to a wire which passes freely through a hole in the centre of C D, and is fixed firmly in the part F G. Now suppose the temperature to rise, the bars A C and B D would be expanded, and the length of the pendulum, that is, the distance between the points E and W, would be increased; but the same rise of temperature causes an expansion also of the copper bars F H and G I, by which the weight W will be drawn up, or this distance between the points E and W will be diminished. Now, as the lengths respectively of these bars of copper and steel are made inversely proportional to their expansibilities by heat, it follows that the length of the pendulum, as a whole, is preserved the same through every ordinary change of temperature; that is, the whole amount of the contraction or expansion of the steel part of the pendulum is just equal to the whole amount of the contraction or expansion of the copper part; and as these changes of length of the two parts are in opposite directions, they just balance each other, and the length of the whole pendulum, by which we mean the distance from the point of suspension E to the weight W, remains unchanged.

The importance of such an arrangement is obvious from the fact that a change of temperature of 30° will cause a variation of about 8 seconds in 24 hours in a common clock with an iron pendulum. If the pendulum is brass or copper, the variation will be still greater. Sometimes pendulum rods are made of wood, which is supposed to be less affected by changes of temperature than the metals.

MECHANICAL POWERS.

113. The mechanical powers are simple machines or instruments, with which we are accustomed to raise weights and overcome resistances. They are six in number, viz. the *Lever*, the *Wheel and Axle*, the *Pulley*, the *Inclined Plane*, the *Wedge*,

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Quest. 113. What are the mechanical powers? How many of them are there? Does each one of these act on a distinct principle?

and the *Screw*. But as the wheel and axle act essentially on the same principle as the lever, and the wedge and the screw on the same principle as the inclined plane, many writers are disposed to reduce the number of the mechanical powers to three, viz. the lever, the pulley, and the inclined plane.

114. All the machines, however complicated, which the ingenuity of man has ever invented, are nothing more than combinations of these simple powers. Though great advantage is gained by the use of machines, there is no such thing, properly speaking, as the creation of power by them, as some have supposed; their design seems to be to exchange time for power, as will appear more fully hereafter.

In the use of any machine, whether simple or complex, three things are to be particularly considered. 1. The force or resistance which is to be sustained or overcome, which we will call the *weight*. 2. The force which is used to produce the effect desired, called the *power*. 3. The mode in which, by the action of the machine, the power produces the proper effect upon the weight.

115. *The Lever.* — The lever is an inflexible rod of metal or other solid substance, capable of moving upon a point of support called the *fulcrum*. In what we have to say of it, no notice will be taken of its own weight.

There are three kinds of lever, or rather three varieties of it, depending upon the position of the fulcrum with reference to the power, or force applied to move it, and the weight, or resistance to be overcome.

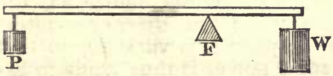

Fig. 42.

116. In the lever of the first kind, the power is supposed to be applied at one extremity, and the weight at the other, with the fulcrum, or point of support between them, as in figure 42, where P is the power, F the fulcrum, and W the weight. If the fulcrum is placed at the centre, it is evident nothing is gained, as the power and weight must be exactly equal in order that they may balance each other; but when the fulcrum divides the lever into two unequal arms, having the weight upon the shorter, then the power will be to the weight as the length of the short arm is to that of the long arm. Thus, if in

Quest. 114. Are all machines merely combinations of those simple powers? Do they create power? What, then, is their design? What three things are to be considered in the use of machines? 115. What is the *lever?* How many kinds or varieties of the lever are there? 116. In the lever of the first kind, how are the power, weight and fulcrum situated with respect to each other? If the fulcrum is in the centre, how must the power and weight compare with each other to produce an equilibrium? What is the ratio of the power to the weight, when the weight is attached to the short arm, and the power to the long arm? How is figure 42 explained? When motion is

the above figure, the arm F W is to F P as 1 to 3, then the power P will be to the weight W as 1 to 3. That is, if the length of the longer arm is 3 times that of the shorter arm, in order to produce an equilibrium the weight must be 3 times the power. In order that the weight may be raised, it is evident the power must be a little increased, so as to exceed one-third of the weight.

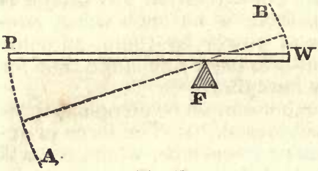

Fig. 43.

When motion is produced by means of this lever, the extremity of each arm moves in the circumference of a circle, the centre of which is at the point of support or fulcrum, as is shown in figure 43; and the arc described by each will be in proportion to its length. Consequently, to raise the weight any distance, as an inch, in the arc W B, supposing the longer arm 3 times the length of the shorter, the power must fall in the arc P A 3 times as far, or 3 inches. This is always found to be the case in the use of machines (§ 122); the space passed over by the power will be to that passed over by the weight, as the weight is to the power.

117. Numerous examples of the use of this kind of lever will readily occur to every one. The common balance, in which the arms are equal, and the steelyards, in which they are unequal, the scissors, pincers, &c., are instances.

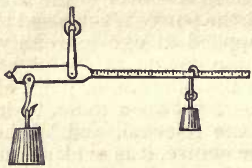
Fig. 44.

In the steelyards, figure 44, the arm on which the power or counterpoise is placed, is variable, so that the same power is thus made to balance different weights; this is the design of the weigher in moving the counterpoise backward and forward, a figure, at the notch in which the counterpoise in a given case may rest, showing the weight which it balances.

In the scissors, the intelligent student will readily determine what is to be considered the power, what the weight, and what the fulcrum.

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produced by means of a lever, do the extremities of the arms move in straight lines? In the use of machines, how does the space passed over by the power compare with that passed over by the weight? 117. What examples of the lever are mentioned? What is the common balance? In the common steelyards, why is the power or counterpoise made so as to move from place to place? How is the weight the counterpoise balances in a particular case, shown? Do scissors act on the principle of the lever? What is to be considered the power, what the weight, and what the fulcrum?

The torsion balance, which has been referred to (§ 36) as furnishing the necessary means of determining the difference in the weight of a body at the equator and at the poles, consists of a coiled spring usually enclosed in a metallic case. One end of it is attached to a fixed support, and the body to be weighed is suspended from the other; and its weight is shown by the distance to which it extends the spring. Consequently, if a body weighs more at or near one of the poles of the earth than at the equator, it must extend the spring further at the former place than at the latter. By means of a balance of this kind, made with great care, and transported from the equator to a high latitude, it is said that the increased weight of bodies in places towards the poles has been made plainly sensible.

The description of this balance is introduced here, so as to be in connection with the remarks on the common balance, and not because it is in any manner in the mode of its action connected with the lever.

118. The second kind of lever is distinguished by having the power at one extremity, and the fulcrum at the other, with the weight between them.

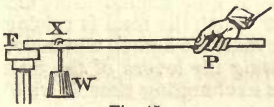

Fig. 45.

In figure 45, which represents a lever of the second kind, the power is to the weight as the distance from the fulcrum F to the point where the power is applied is to the distance from the fulcrum to the point to which the weight is attached; that is, the power is to the weight as F X is to F P.

An example of the use of this kind of lever is seen in the case of two men carrying a burden on a pole between them, one of whom may be considered the fulcrum and the other the power. It is evident the burden may be so suspended between them that any given portion of its weight may fall upon either one of them. As other examples of this kind of lever, common nut-crackers, chipping-knives, and treadles to lathes may be mentioned.

119. The third kind of lever is that in which the fulcrum is at one extremity, and the weight or resistance at the other, while the power is applied between them.

Quest. 118. How is the second kind of lever distinguished? In figure 45, what is the ratio of the power to the weight? What examples of the use of this kind of lever are mentioned? If two men are carrying a weight on a pole between them, how must it be placed so that each shall sustain just one half of it? 119. What is the third kind of lever? In the use of this kind of lever, which must be greatest, the power or the weight? Is the object of the lever always to gain power? When a man raises a ladder against the side of a building, what is to be considered the power, weight and fulcrum? Is he obliged, in raising it, to lift more than its weight? In the use of this kind of lever, does the weight or power move through the

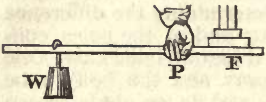

Fig. 46.

It is illustrated in figure 46, in which F is the fulcrum or prop, P the power, and W the weight as before. In the use of this kind of lever, it will be seen, there must be always a loss of power; or, in other words, the power must always be greater than the weight.

The object of the lever is not, therefore, in all cases, to gain power; there may be other motives for using it. A man raising a ladder against the side of a building is an instance of the third kind of lever; the ladder itself is the weight, and the building against which its foot is placed is the prop or fulcrum, and the man is the power. Now, he might adopt other means to raise the ladder, in which less physical strength would be required; but notwithstanding this disadvantage, he still finds it more convenient, on the whole, to raise it in this way than to resort to another method.

In the use of this lever, it will be observed, the weight moves through a greater distance than the power, contrary to what takes place when the levers of the first and second kind are employed. Thus, the top of the ladder which the man is raising passes over a much greater distance than his hands, which are considered the power. If, then, in using the levers of the first two kinds, we may be considered as exchanging time or velocity for power, in using this kind we make the reverse exchange, and gain time by applying greater power.

The most striking examples of the third kind of lever, we are informed by anatomists, are found in the animal economy. Most of the limbs of animals are levers of this description; the socket of the bone is the fulcrum, a strong muscle attached to the bone near the socket is the power, and the limb itself, with any body connected with it, is the weight. The fore-arm, extending from the elbow to the wrist, affords an excellent instance. The arm-bone, which connects with one of the fore-arm bones at the elbow, is the fulcrum; the large muscle lying on the fore-side of the arm-bone, is the power; and the hand, with anything contained in it, is the weight. The hand is raised by the contraction of the muscle, the motion of which can readily be felt by placing the left hand upon the right arm above the elbow, and then making an effort with the right hand, as if to raise a heavy substance.

It is evident that, by this arrangement, to raise a weight in the hand, the force exerted by the muscle must be much greater

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greater distance ? Where do we find the most striking examples of this kind of lever ? In the fore-arm, what is the power, what the weight, and what the fulcrum ? How does the muscle raise the hand ? In order to raise the hand, must the muscle exert a greater force than if it were applied directly to the hand ? Is it essential that the lever should be straight ?

than if it were applied directly to the weight; but this disadvantage is more than compensated by other advantages equally important.

It is not essential that the lever should always be straight; it may be curved in different directions, or even bent at right-angles, and the result will be the same. The hammer with which a carpenter draws a nail from a piece of wood may be considered a lever, the arms of which make a right-angle with each other.

120. Simple levers are sometimes so combined, that one, instead of acting directly on the weight, acts on a second, and this on a third, &c.; and the last exerts the combined effect of the whole on the weight. Such a combination of levers is called a *compound lever*.

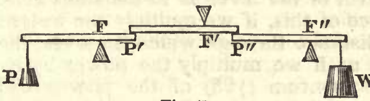

Fig. 47.

In figure 47, we have a system of levers of this kind. To calculate the ratio of the power to the weight, let us suppose that the long arm of each simple lever is just twice the length of the short arm; then P will be to P′ as 1 to 2, and P′ to P″ as 2 to 4, and P″ to W as 4 to 8. Therefore, 1 pound at P will just balance 8 pounds at W, or the power is to the weight as 1 to 8.

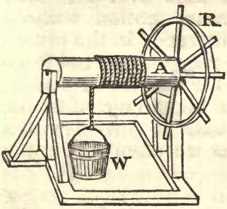

Fig. 48.

121. *The Wheel and Axle.*—The wheel and axle, as already intimated (§ 113), is generally considered merely as a modification of the lever. It is represented in figure 48, and consists of a cylinder, A, termed the axle, around which a cord is wound, turning on a centre, and connected with a wheel, R. The resemblance of this mechanical power to the lever will be best seen by a side view of the wheel, as in figure 49, in which R is the wheel, and A one end of the axle, P the power, W the weight, and the point of support the fulcrum. It is evident that the radius of the wheel A C becomes the long arm of the lever, and the radius of the axle A B the short arm; consequently, (§ 116), the power must be to the weight as the radius of the axle is to the radius of the wheel.

Quest. 120. What constitutes the *compound lever?* If three levers are combined in this manner, each having its longer arm twice the length of the shorter, what will be the ratio of the power to the weight? 121. What is the wheel and axle usually considered? Of what two parts does it consist? What is to be considered the long arm of the lever, and what the short arm? What will be the ratio of the power to the weight? If the wheel is turned once round, how far will the weight and power move? How much greater

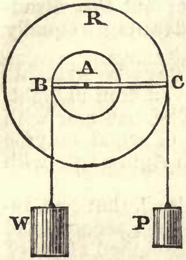

Fig. 49.

If we suppose the wheel to be turned once round, it is plain the power will fall a distance just equal to the circumference of the wheel, while the weight will be raised a distance equal to the circumference of the axle. But the circumferences of circles are to each other as their radii; hence the distance passed over by the power is as much greater than that passed over by the weight as the radius of the wheel is greater than the radius of the axle; or, more correctly stated, the distance passed over by the power is to the distance passed over by the weight as the radius of the wheel is to the radius of the axle; that is, as the long arm of the lever is to the short arm. As a necessary consequence of this, if we multiply the weight by its velocity, or by the distance through which it moves, the product will be the same as if we multiply the power by its velocity. That is, the momentum (§ 95) of the power will always be just equal to that of the weight. Let us suppose, for instance, that the circumference of the wheel is 9 feet, and that of the axle 3 feet, then the power will be to the weight as 1 to 3; if we turn the wheel round once, the power will move 9 feet, and the weight 3 feet. But $1 \times 9 = 3 \times 3 = 9$.

122. The advantage of the wheel and axle over the lever consists in its allowing a longer continued motion without cessation. Manifestly it can make no difference in the principle upon which this mechanical power acts, whether the force is applied directly to the rim of the wheel by means of a rope, or whether there are pins in the rim to be taken hold of by the hands, as in figure 48, or whether the axle is turned with a crank or a single movable handspike, as we often see, in the use of the windlass, on board of ships.

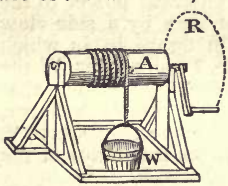

Fig. 50.

Indeed, in every case, it is easy to see that the power describes a circle as really as when the wheel is used. Thus, in figure 50, the hand applied to the crank revolves in the circle R, and the power is to the weight as the radius of the axle is to the length of the crank.

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is the distance passed over by the power than that passed over by the weight? If we multiply the power by its velocity and the weight by its velocity, how will the products compare? 122. In what does the advantage of the wheel and axle over the lever consist? Will it make any difference in the principle upon which this machine acts, whether the power is applied to the rim of a wheel, or whether the axle is turned by a handspike or crank? What is

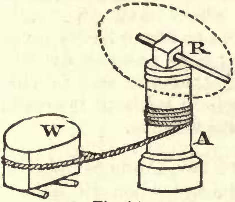

Fig. 51.

The *capstan*, figure 51, is merely an upright axle with a horizontal wheel, R, or a crank, which is equivalent to it. The advantage of the capstan over the ordinary wheel and axle consists in its allowing the workman to walk around it, as he terms it, to move the weight.

123. Wheels and axles may be combined to produce a compound machine, much in the same manner as the system of levers. Examples of the kind are seen in clocks and watches, and in almost all kinds of machinery.

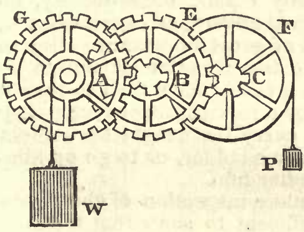

Fig. 51 *a*.

Figure 51*a* represents a system composed of three wheels which act upon each other by means of teeth; the teeth in the circumference of one wheel connecting with those in the axle, usually called the pinion, of the next. To estimate the mechanical power of such a system, or the ratio of the power to the weight, we have only to multiply together the number of teeth in the wheels, and also the number in the pinions, and the products thus obtained will themselves express the ratio required. Suppose each of the wheels F E G to contain 30 teeth, or to be of sufficient diameter to contain this number, and each of the pinions C B A only 5; then $30\times30\times30=27000$, and $5\times5\times5=125$. Consequently, the power P is to the weight W as 125 to 27000; or, which is the same thing, as 1 to 216. Therefore, 1 pound at P will balance 216 pounds at W.

Instead of teeth, the wheels are often furnished with bands, by the friction of which the motion is communicated from one wheel to the other. In such cases the wheels may be placed at considerable distances from each other, which is often of great importance.

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the *capstan?* How does it differ from the wheel and axle? 123. How are several wheels and axles sometimes combined so as to act upon each other? How are they connected? How is the ratio of the power to the weight to be calculated? If there are three wheels with 30 teeth each, as in figure 51 *a*, with pinions having each only 5 teeth connected together, how many pounds at W will be required to balance 1 pound at P? How is this number obtained? Are the wheels always made to act upon each other by means of teeth? Why are bands sometimes used?

124. *The Pulley.*—The mechanical power usually called a pulley, in its simplest form, consists of a wheel having a groove in its circumference, so fixed in a block as to move freely upon a pivot in its centre, and having a cord or rope passing over it. It will be seen, however, as we proceed, that the use of this wheel is only to diminish the friction, which without it would be so great as to render the machine quite useless.

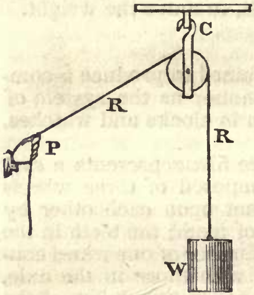

Fig. 52.

125. There are two kinds of pulleys, the fixed and the movable. Figure 52 is a fixed pulley, C the wheel, sometimes called the sheave, R R the cord, P the power, and W the weight. It is very evident that the power and weight, to balance each other, must be exactly equal; consequently, no mechanical advantage is gained by it. But it is of great importance often in changing the direction of motion, as it is much easier for a man to raise a weight by a rope passing over a pulley than to carry the weight up a flight of stairs or a ladder, or to go up himself, and then pull the weight up after him.

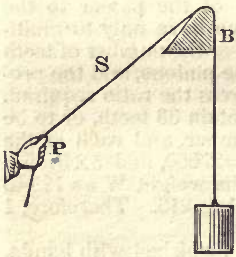

Fig. 53.

126. A mere inspection of the figure is also sufficient to show that the only use of the wheel or sheave is to diminish the friction; for if the cord, S, figure 53, passed over a block of wood, B, in order that the power and weight may balance each other, they must be equal. But if sufficient power is to be applied to raise the weight, there would be great loss by reason of the friction of the cord upon the wood. The cord and the block would also be so rapidly worn away as to render it entirely useless in practice.

Though no direct mechanical advantage is ordinarily gained by the use of a fixed pulley, yet a man may raise himself by means of it by exerting a force equal to only half his weight.

Quest. 124. What is the pulley? What is the use of the wheel? 125. What two kinds of the pulley are there? How must the power and weight compare in order to balance each other over a single fixed pulley? Why is the fixed pulley still used if no mechanical advantage is gained by it? 126. What would be the effect if the cord was made to pass over a block of wood instead of a wheel? How may a person raise himself by means of a fixed pulley? What part of his own weight would he have to draw up with his


Fig. 54.

Thus, let a man be seated in a chair having one end of a rope attached to it; the other end, after passing round a fixed pulley, returning to his hand, as represented in figure 54. If he now pulls downward by an amount equal to half his weight, he will be supported, one-half by the direct effort of his hands, and the other half by the chair. This is sometimes found a very convenient method for a person to let himself down into a well, and to draw himself out again.

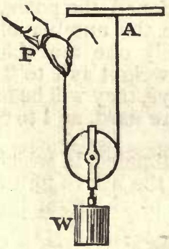

Fig. 55.

127. The movable pulley is represented in figure 55. In this, one end of the cord is attached to a fixed support, A, and to the other end the power is applied. As both parts of the cord will have an equal tension, it is evident one-half of the weight W will be sustained by the hook A, and the other by the power P; hence, the power will be to the weight as 1 to 2. Instead of pulling upward with the hand, as represented in the figure, it is usual to have the cord passed over another fixed pulley.

128. In raising a weight by a single movable pulley, as just described, it will be seen the power has to pass over twice the space which is traversed by the weight; that is, as in the case of the lever, (§ 116), or the wheel and axle, (§ 121), the space passed over by the power is to that passed over by the weight as the weight is to the power. That the power has to pass over twice as much space as the weight, will be evident from the consideration that, to raise the weight 1 inch, both cords which support it, or rather both parts of the cord, must be shortened an inch, which would require the hand to move 2 inches.

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hands? 127. When the fixed pulley is used, by how many cords is the weight supported? How many support it when a single movable pulley is used? What then is the ratio of the power to the weight? 128. When a single movable pulley is used, how much more space must the power pass over than the weight? How does this appear?

Fig. 56.

129. Usually, in practice, several pulleys are combined, as is shown in figure 56. Here are two fixed pulleys in the block A, and two movable ones in B; and the weight W is sustained by four cords, or, which is the same thing, by four parts of the same cord. As all parts of the cord are equally extended, each of them of course sustains one-fourth part of the weight; or the power P is to the weight W as 1 to 4. In other words, a power of 1 pound is made to counterpoise a weight of 4 pounds.

In this instance it will be perceived, that in order to raise the weight 1 inch, each of the ropes must be shortened an inch, which will require the power to move through 4 inches; which also accords with the maxim that what is gained in power is lost in time.

130. There may be more than two fixed and two movable pulleys used, but in every case, with a single exception shortly to be mentioned, the power will be to the weight as 1 to twice the number of movable pulleys. Thus, when only one movable pulley is used, the power is to the weight as 1 to 2; when there are two movable pulleys, they will be to each other as 1 to 4; when three are used, as 1 to 6, and so on.

131. There is, indeed, one case, as above intimated, in which this rule requires to be slightly modified. In the above figure (56) it will be seen, the rope is attached to the block containing the fixed pulleys at C; if, instead of this, it had been attached to the block containing the movable pulleys, as at D, then it is plain there would have been five ropes to sustain the weight, each of which would sustain a fifth; and the power would be to the weight as 1 to twice the number of movable pulleys, plus one; or as 1 to 5. In this case, one more fixed pulley would have been required.

Instead of having the pulleys placed one above another, as represented in figure 56, in practice they are usually placed side by side, but the result is the same.

Quest. 129. In practice, is the pulley ordinarily used singly? When there are two fixed and two movable pulleys, by how many cords is the weight sustained? How many pounds at W will a power of 1 pound at P counterpoise? How far must the power P move in order to raise the weight 1 inch? How does this appear? 130. When more than two movable pulleys are employed, how will the power be to the weight? If there are eight movable pulleys, how many pounds at W will 1 pound at P be sufficient to counterpoise? 131. What exception to this rule is mentioned? If, in figure 56, the cord was attached to the movable block, what would be the ratio of the power to the weight? Is it necessary that the sheaves or wheels in the same block should be placed one above another?

132. Sometimes the cord, or rope, instead of being entire, as represented above, is divided into several parts, each pulley hanging by a separate string, one end of which is attached to a fixed beam.

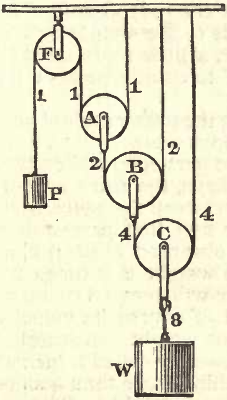

Fig. 57 *a*.

By this arrangement, which is seen in figure 57*a*, we gain a great increase of power, attended by a corresponding loss of time. We may estimate the power gained as follows: First, the power P, which we will suppose 1 pound, exerts its force on the movable pulley A, over the fixed pulley F, the other end of the cord being attached to the beam above. The pulley A is therefore drawn upward by a force of 2 pounds. But the first movable pulley A is connected with the second pulley B, by the cord 2, 2, in the same manner as the weight P is with A by the cord 1, 1; consequently, the pulley B must be drawn upward by a force of 4 pounds. In like manner it may be shown that the third movable pulley C must be drawn upward by a force of 8 pounds. Or, we may commence with the weight W, which we will suppose to be 8 pounds; as it is sustained equally by the two parts of the cord 4 and 4, each part must support one-half, or 4 pounds. So, the pulley B, which sustains a weight of 4 pounds, is supported equally by the two cords 2 and 2, each of which of course sustains one-half, or 2 pounds. In like manner the pulley A is supported by two cords, each of which sustains 1 pound. By this arrangement, therefore, a power of 1 pound is made to balance a weight of 8 pounds; or, in other words, the power is to the weight as 1 to 8. If another pulley were added, it is evident the weight which the same power would sustain would be doubled, or the power would be to the weight as 1 to 16.

In estimating the effect of particular systems of pulleys, we have left out of the account the weight of the blocks and pulleys themselves, which is sometimes considerable. Usually, they operate against the power; that is, a portion of the power is required to be expended to counterbalance their weight; but, in some cases, they are made to act in favour of the power.

Quest. 132. How is the action of the system of pulleys in figure 57 *a* explained? What weight at W will 1 pound at P sustain? If another pulley were added, what would be the ratio of the power to the weight? What is a system of pulleys called? In the above estimates, has the weight of the pulleys themselves been taken into account? What is the proportion of the power to the weight in the system represented in figure 57 *b*?

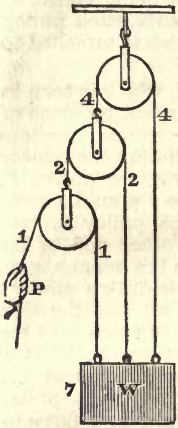

Fig. 57 *b*.

Such a case is seen in figure 57 *b*. One pulley, it will be seen, is fixed; but the weight of the other two assists the power P to counterbalance the weight W. The figures by the side of the cords show the part sustained by them; and the power is to the weight as 1 to 7. In reality, however, a little more must be added to the weight W to counterbalance the two pulleys.

Other modes of using the pulley are not here discussed, nor the various methods that have been adopted to obviate particular difficulties. In every system of pulleys, the same proportion, so often noticed, between the space passed over by the power and that passed over by the weight, will be observed, (§ 122;) if, as in the above case, the weight is 8 times the power, then the power will move 8 times as far as the weight, and of course its velocity will be 8 times that of the weight. In practice, a system of pulleys is usually called a *tackle*.*

133. *The Inclined Plane.*—This is nothing more than a slope or declivity frequently used for drawing up weights. The advantage gained by it will always be in proportion as the length of the plane is greater than its height.

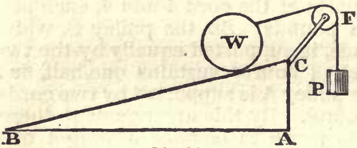

Fig. 58.

In the inclined plane B C, figure 58, let us suppose that B C is five times A C; then, in order to produce an equilibrium, the weight W must be five times the power P, the cord connecting them being supposed to pass over the fixed pulley F. To understand how this effect is produced, the weight W may be supposed to be divided into two parts, one of which, equal to four-fifths of it, is supported directly by the plane itself, while the other part, equal to one-fifth, tends to carry it down the plane, and is supported by the power P. If the weight is drawn up from B to C, it is evident the power P must pass through five times the perpendicular distance the weight W does. For, suppose the weight to be at B, and the power at F, the cord extending from P to W; as the weight W ascends from B to C, rising perpendicularly the

Quest. 133. What is the *inclined plane?* In what proportion will be the advantage gained by it? If the length of the plane is five times its height, what will be the ratio of the power to the weight? If the power sustains but one-fifth of the weight, how are the other four-fifths supported? In drawing

* By sailors, this word is generally pronounced tā-kel.

distance A C, P must descend a distance equal to B C, which is 5 times A C. Therefore, though it requires only one-fifth as much force to raise the body up the inclined plane that would be necessary to raise it perpendicularly, yet it has to move five times as far, and with the same velocity it of course would require five times as much time. The same principle just discussed, (§ 121), will again be here noticed.

The velocity a body will acquire in falling down an inclined plane, (making no allowance for friction,) is the same as it would acquire in falling freely through an equal perpendicular height. That is, a body falling from C to B, down the inclined plane, will attain precisely the same velocity as if it fell perpendicularly from C to A.

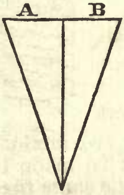

Fig. 59.

134. *The Wedge.*—The wedge is composed of two inclined planes, as A and B, figure 59. It is little used except in cases where a great force is to be exerted only at very small distances. The advantage gained by it is generally considered to be in proportion to its length as compared with half its thickness. In practice, too, it allows percussion to be used, instead of simple pressure, by which the effect is greatly increased; but its power cannot be very accurately calculated.


Fig. 60.

The wedge is much used in splitting wood, (as in figure 60,) and other substances; and, indeed, several of our domestic instruments are modifications of it, as the knife, chisel, axe, &c. Needles and pins may also be considered as very acute wedges.

135. *The Screw.*—The screw is always composed of two parts, the external and the internal screw. The external screw consists of a cylinder with a spiral protuberance winding round it, called the thread. It is well represented by taking a cylinder A B, figure 61, and winding round it a piece of paper cut in the form of a right-angled triangle. The hypothenuse of the triangle will form the thread, which differs in nothing from the inclined plane except its spiral form.

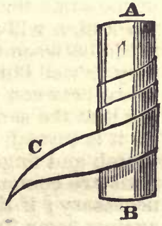

Fig. 61.

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up the weight through the length of the plane, how much farther perpendicularly will the power move than the weight? 134. What is the wedge composed of? In what cases is it chiefly used? In what proportion is the advantage gained by it? For what purpose is the wedge much used? Can its power be accurately calculated? 135. Of what two parts is the screw composed? What does the external screw consist of? How may it be represented?

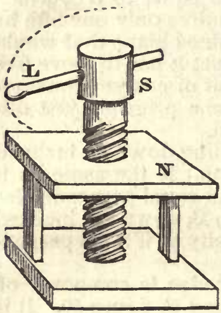

Fig. 62.

136. The internal screw is sometimes called the nut, and consists of a block with a cylindrical hole, having the thread or spiral protuberance so cut inside, that the thread of the external screw will exactly fit between them. In figure 62, S represents the external screw, and N the internal screw or nut.

The thread of the screw may be cut square, as in A, figure 63, or wedge-shaped, as in B; but it is more frequently seen of the latter form, especially when made of wood.

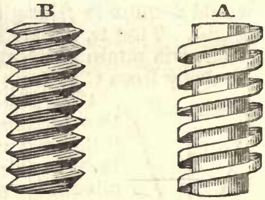

Fig. 63.

137. In using the screw as a mechanical power, two motions are necessarily produced; one of the parts must be made to revolve on its axis, and one or the other must at the same time advance in the direction of the length of the cylinder on which the external screw is cut. In figure 62, the external screw is supposed to be turned by means of the handle L; and it is plain it must at the same time advance either upward or downward according to the direction in which it is turned. But this arrangement is not essential; the parts may be so formed that either one may revolve and either one advance, but not both at the same time. Whichever part is made to revolve, a single revolution will always cause an advance just equal to the distance between the threads. These two motions of the screw may be well illustrated by grasping firmly the thread of a small screw between the thumb and finger of the left hand, and turning it at the same time by the right hand applied to the head. As it is turned, it at the same time passes through between the thumb and finger in the direction of its length. Here both motions are communicated to the external screw, but this is not necessary; if the head of the screw, as it is termed, is held against some fixed body, the thumb and finger, which constitute the nut, will move in the direction of the length of the screw.

Quest. 136. What does the internal screw consist of, and what is it called? In what two forms is the thread of the screw cut? 137. When the screw is used, what two motions are produced? In figure 62, which is supposed to be turned, and which part advances? How far will the screw advance by a single revolution? How may these two motions of the screw be illustrated?

138. If the screw were used in this simple form without a lever, the advantage gained by it would be in proportion as the distance round it is greater than the distance between the threads, the former of which may be considered the length of the inclined plane, and the latter its height (§ 133). But the screw is seldom if ever used without a lever (as L, figure 62) to turn it, by which its power is greatly increased. The advantage thus gained by it will be as the circumference of the circle described by the end of the lever, is to the distance between the threads.

There are, therefore, two methods by which its power may be increased, either by diminishing the size of the threads, or by increasing the length of the lever which is used with it.

Let us suppose it is required to calculate the power of a screw, the threads of which are $\frac{1}{4}$ of an inch apart, and the lever with which it is turned is $3\frac{1}{2}$ feet long, and of course describes a circle, when the screw is turned, 22 feet in circumference. The power (§ 114) must be to the weight as the distance between the threads ($\frac{1}{4}$ inch) is to the circumference of the circle described by the lever (22 feet). We have then the following proportion:

As $\frac{1}{4}$ inch : 22 ft.=264 inches :: 1 : 1056; by which it appears that a force equal to 1 pound applied to the lever will balance a pressure of 1056 pounds upon the screw. But it is to be observed that in the use of the screw, the loss from friction is so great, that its power cannot be calculated with any considerable accuracy.

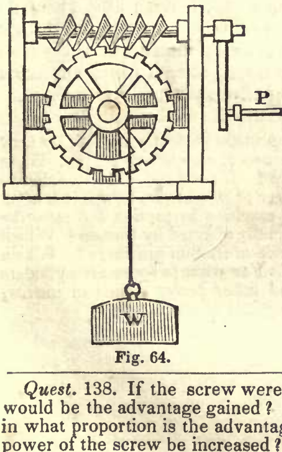

Fig. 64.

139. Sometimes the threads of a screw are made to act upon the teeth of a wheel so as to turn it, as in figure 64; it is then called an *endless* or *perpetual screw.*

The screw is used in almost an endless variety of operations in practical mechanics, but chiefly in cases where a great pressure is to be exerted through small distances.

Quest. 138. If the screw were used without a lever, in what proportion would be the advantage gained? When the lever is used to turn the screw, in what proportion is the advantage gained? By what two methods may the power of the screw be increased? Suppose the threads of a screw are $\frac{1}{4}$th of an inch apart, and the lever with which it is turned $3\frac{1}{2}$ feet in length, what will be the ratio of the power to the weight? 139. How is the *perpetual* screw constructed? For what purposes is the screw used?

140. *Friction.*—The general subject of friction has already been referred to (§ 54), but its important effect upon the operation of the mechanical powers requires that it should be again introduced. Surfaces, however well they may be polished by art, are not perfectly smooth; and when they come in contact, more or less force is always required to cause one to move over the other, as is necessary in the working of machinery.

141. In the preceding investigations, no allowance has been made for friction, as the object has been merely to calculate the ratio of the power to the weight when in a state of perfect equipoise; but, if the weight is to be raised, friction must necessarily be produced between the different parts of the machinery; and, in order to overcome it, the power must be considerably increased above what has been estimated. As a general rule, the loss from friction is supposed to be equal to about one-third of the power which is applied; that is, if, by the use of a machine, a weight of 150 pounds is exactly balanced by a power of 30 pounds; then to put the weight in motion will require an addition of one-third of the original power, or 10 pounds, making 40 pounds in all.

But the resistance of friction in some of the mechanical powers is much greater than in others; the lever is least affected by it, while in the screw and wedge it is enormous.

142. Friction is of two kinds, the one occasioned by a body gliding over another; the other by the rolling of a circular body. The latter is usually much less than the former. Owing to this, friction-rollers are sometimes used with the view to diminish the resistance. So cylinders of wood are placed under very heavy masses, as buildings, in moving them, for the same purpose. Where rollers cannot be used, the rubbing surfaces are generally lubricated by smearing them with oil or grease.

Quest. 140. Can the surfaces of bodies be made perfectly smooth by art? Why is there always a loss of power in the use of machinery? 141. What allowance for this loss is usually to be made? If a weight of 150 pounds is balanced by the use of a machine by a power of 30 pounds, how much additional power will be required to put the machine in motion and raise the weight? Are all the mechanical powers equally affected by friction? Which is least affected by it? 142. What two kinds of friction are there? Which is the greatest? What are friction rollers? For what purpose are cylinders of wood usually placed under buildings and other heavy bodies in moving them? What is the object of greasing the joints of machinery?

CHAPTER II.

HYDROSTATICS.

143. THIS branch of science treats of the nature, pressure, and motion of fluids in general, and their relation to solids.

A fluid is a substance that yields to the slightest pressure. There are two kinds of fluids, liquids and gases; but in this chapter we propose to confine ourselves entirely to the former.

144. Fluids are subject to all the laws developed in the preceding pages, only with such modifications as depend upon their peculiar constitution; they obey strictly the laws of gravitation and motion in cases where the ready mobility of their particles does not interfere. A mass of water or other fluid, in falling from a height, would produce the same effect as an equal mass of a solid, if no opposing cause existed; and the reason why no one fears the fracturing of his skull by the dashing of a quantity of water upon him from an elevation, is because the particles are so easily separated from each other; the mass is broken merely by the resistance of the air, and consequently the momentum of the whole cannot be made to act on a single point, as is the case with solids. If the particles of the mass are made to cohere by freezing, then its mechanical effects will be the same as those of any other solid.

145. Liquids are slightly compressible. This was for a long time doubted; but, from the result of many very accurate experiments, it is found that water, which may be considered as the representative of liquids in general, is diminished in volume about 46 millionths by a pressure of fifteen pounds to each square inch. An apparatus has been constructed which shows this in a very satisfactory manner.

Quest. 143. Of what does the branch of science called Hydrostatics treat? What is a fluid? 144. Are fluids subject to the laws which have already been discussed? Do they obey the same laws of gravitation as solids? Why do not fluids in falling produce the same mechanical effects as solids? If the particles of water are made to cohere by freezing, what would be the effects of the falling of a mass? 145. Are liquids compressible? By what part of its volume is water compressed by a pressure of 15 pounds to the square inch? How is the apparatus constructed which is used to demonstrate the compressibility of liquids? When the pressure is removed, will the liquid possess the same volume as at first? Are all liquids equally compressible?

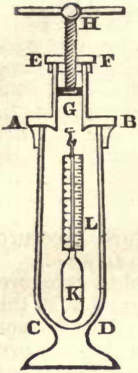

Fig. 65.

Let A B C D, figure 65, be a strong glass vessel, having firmly cemented on its upper part, A B, a short metallic cylinder, E F, with a piston, G, fitting into it perfectly tight, and capable of being moved up and down by the screw, H. K is a bottle, having its neck drawn out into a small tube, to which a scale, L, is attached, graduated to small parts of an inch. This bottle is first to be filled with water quite to the top of the tube, and then a minute globule of mercury is to be introdúced, so as to rest upon the surface of the water. Let us suppose that by trial it is found that 1 inch of the tube forming the neck of the bottle is capable of containing just 80 millionths as much as the bottle. The bottle, with its tube and scale, is now to be placed in the large glass vessel, which is then to be filled with water, and the piston inserted. By turning the screw, the piston is forced down, and all the water, both within and without the bottle K, equally compressed; and the diminution of volume of that within the bottle will be indicated by the descent of the globule of mercury in the neck of the bottle K. If the globule is seen to fall an inch, then it is plain the water has been compressed 80 millionths of its volume; if the globule is made to fall 2 inches, the compression will be 160 millionths of the original volume, and so on. When the piston is raised, and the pressure removed, the globule of mercury will rise to its original position, showing that water is really elastic.

By this means it has been determined that all liquids are compressible; but each has a compressibility peculiar to itself, some being more and some less compressible than water.

Fig. 66.

146. In order to determine the amount of pressure to which the liquid is at any time subjected, a small glass tube, figure 66, closed at the top, and open at the bottom, is placed inside the apparatus with the bottle K. This tube being filled with air, the water cannot rise in it except as it compresses the air before it (§ 8), which it is known (as will hereafter appear) is diminished in volume by just one-half for every 15 pounds' pressure, or one atmosphere. The tube being carefully graduated to fractions of an inch, when by screwing down the piston the water is seen to rise half-way in it, we know the pressure to be equal to 15 pounds to the inch, which is called one atmosphere; when the water rises so as to fill one-half of the remainder of the tube, or three-fourths of the whole, the pressure will be equal to three atmospheres, or 45 pounds to the inch, and so on.

If this seems obscure to the young student, let him recollect that when the tube is placed in the apparatus, it is under the pressure of 1 atmosphere—the ordinary atmospheric pressure—and when this is doubled, or the pressure increased to 2 atmospheres, the water will rise so as to fill half the tube. If this pressure is again doubled, or the pressure increased to 4 atmospheres, one-half of the remainder space, or three-fourths of the whole tube, will be filled with water; but, in these 4 atmospheres, the ordinary

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Quest. 146. How is the amount of pressure determined? How much is the volume of air diminished by a pressure of 15 pounds to the inch?

atmospheric pressure is included, so that the pressure applied by the apparatus will be equal to 3 atmospheres.

This subject will be made plain in the Chapter on Pneumatics.

147. Though the particles of liquids move freely amongst themselves, there is, as we have heretofore seen, a slight attraction between them, as is shown by their adhering together to form the drop. But it is very slight; and each particle may therefore be considered as gravitating towards the earth by itself alone, entirely independent of the others by which it is surrounded.

148. As a natural consequence of this, a mass of any liquid always takes the form of the vessel in which it is contained, however irregular it may be. By taking advantage of this peculiarity of liquids, solids that are capable of being melted are cast into any form which is desired. The solid is first melted, and while in the liquid state poured into a vessel or cavity of the proper form previously prepared; and when it has solidified by cooling, it is found upon removal from its bed to be of the shape required.

149. As another consequence of this property of liquids, their surfaces will always be found when at rest to be perfectly level; every particle at the surface will be equally distant from the point to which they all tend. This point, we know (§ 26), is the centre of the earth; and hence the surface of a fluid must always partake of the spherical form of the globe. This is evident in large bodies of water, as the ocean; but the sphericity of small bodies is so trifling in consequence of the great distance of the centre, that their surfaces appear to the eye perfectly flat.

If, however, the extent of surface is considerable, its spherical form becomes evident. Thus, when a ship is first seen in the distance at sea, only the tops of her masts appear in view; but, as she approaches, more and more of her sails are seen, until at length the whole ship becomes visible. So, when the sailor wishes to see a great distance, he ascends to the mast-head with his telescope, knowing that in consequence of the spherical form of the surface, objects may be seen from that elevation which are entirely hid from his view when upon the deck.

Quest. 147. Do the particles of liquids possess any attraction for each other? How is the slight cohesion of the particles shown? How do the particles of liquids gravitate? 148. Why does a portion of a liquid in a vessel always take the form of the inside of the vessel? How are metals and other solids cast in particular forms which may be desired? 149. Why is the surface of a liquid at rest always level? Towards what point does every particle of a liquid tend to fall? Is the surface of a liquid at rest a plane? Why is not the convexity of the surface apparent in small bodies of water? Why is the top of the mast of a ship at sea visible before the lower parts? Why does a seaman ascend the mast of his ship with his telescope when he wishes to see a great distance? Suppose a line two miles long drawn perfectly straight

But even in bodies of water of comparatively limited extent, the curvature of the surface is not entirely imperceptible. If we suppose a lake two miles in diameter to be frozen over with fine smooth ice, and a line drawn across it perfectly straight, touching the ice in the centre, each end of it would be no less than 8 inches above it.

150. *Pressure applied to Liquids.* — Liquids, on account of the great mobility of their particles, are capable of communicating any pressure exerted on them, equally in all directions.

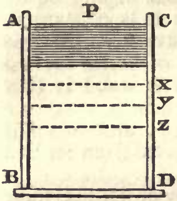

Fig. 67.

To understand this, let A B C D, figure 67, be a vessel filled with water or some other liquid, and P, a solid piston, fitting exactly the inside of the vessel, so that none of the liquid can pass by it. For the present, leaving the weight of the liquid itself out of the account, if P weighs ten pounds, this force will be sustained by the first stratum, x, of the fluid; and this by the next stratum, y; this by the next, z; and so on to the bottom of the vessel, by which the whole will be supported. If the liquid were removed, the piston would at once descend and rest upon the bottom directly, by which it would be sustained; but this is done as really when the liquid is contained within, its weight or pressure being transmitted by the liquid to the bottom.

If, while the piston is in the position represented in the figure, the water should be frozen, supposing it not to adhere to the sides of the vessel, it is plain that the piston would rest upon the ice, and the ice upon the bottom of the vessel; or, in other words, that the pressure of the piston would be transmitted by the ice to the bottom of the vessel. But the mere circumstance of the water being frozen cannot change the transmission of the pressure; the weight or pressure of P must be sustained by the bottom alike in both cases.

151. But as the shape of the fluid will conform to the bottom of the vessel accurately, if the whole surface of the bottom is pressed by a force of 10 pounds, one-half of it will of course sustain 5 pounds, one-tenth 1 pound, and so on; that is, if we suppose the surface of the bottom of the vessel to contain 10 square inches, each inch will sustain a pressure of 1 pound.

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over the surface of a frozen lake, so as just to touch the ice in the middle, how high would each end be above the ice? 150. In what directions do fluids transmit a force impressed upon them? How is figure 67 explained? Would the water as really support the piston when liquid as when frozen? 151. If the whole surface of the bottom is pressed by a force of 10 pounds, how much will be the pressure upon one-half or one-tenth of it?

152. Thus far we have spoken only of the pressure upon the bottom of the vessel; but, in consequence of the freedom of the particles to move among each other, the same pressure will be transmitted to the sides of the vessel also; and if an aperture be made, the liquid will gush out with the same force as if made at the bottom. If an aperture be made at the side, just equal in size to the piston, the force required to be applied to a second piston inserted in this aperture to keep the liquid in, will be precisely equal to the weight of the first piston, or ten pounds. If the aperture in the side be only half or a quarter as large as the piston P, and a second piston inserted, then only a proportional force will be required to keep it in its place.

Again, if a perforation be made in the piston P itself, the liquid will rush upward from below in a jet d'eau, which shows that there is also an upward pressure. Upon trial, this upward pressure would be found precisely equal to the downward or the lateral pressure, which proves that liquids transmit forces acting on them equally in all directions.

153. Some very important consequences result from this property of liquids to transmit force equally in all directions.

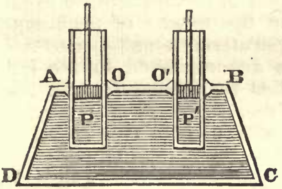

Fig. 68.

Let A B C D, figure 68, be a close vessel, the top of which is horizontal, and O O′ two apertures having tubes inserted in them, which shall be just an inch square inside; and let P P′ be pistons accurately fitted into these tubes. Let us now suppose the vessel filled with water, and a weight of 1 pound applied to one of the pistons; it is plain that every square inch of the internal surface of the vessel would receive a pressure of one pound, which would be shown by the rise of the other piston, if it were not loaded by a weight equal to that placed upon the first. If, therefore, the whole internal surface of the vessel is supposed to contain 1000 square inches, a load of one pound applied to one of the pistons produces a pressure upon the vessel of 999 pounds; and so in proportion to any other weight applied to the piston.

Quest. 152. Is there a pressure against the sides of the vessel as well as against the bottom? If an aperture was made in the side of the vessel of equal size with the piston, and a second piston inserted into it, what weight would be required to keep it in its place? If an aperture was made in the piston P itself, what would be the result? Would the upward pressure be equal to the downward or the lateral pressure? 153. If the internal surface of a vessel be supposed equal to 1000 square inches, and an aperture an inch square be made, and a pressure of a pound be applied by means of a piston, how much force will be exerted upon the whole inside of the vessel? If a second piston be inserted of the same size of the first, when the first is loaded with the weight of a pound, what will be the effect upon the second?

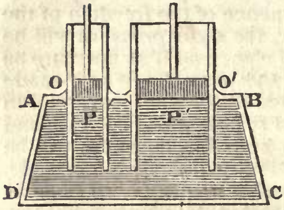

Fig. 69.

154. In the above case we have supposed the two pistons equal; but let us suppose now that the tube O′, figure 69, is ten times as large as the tube O, and the piston P′ of course ten times as large as P. If the piston P be loaded with a weight of 1 pound, a corresponding pressure will be transmitted to every portion of the internal surface of the vessel A B C D; but the piston P′ being ten times as large as P, it will require a load of 10 pounds to counterbalance the 1 pound upon P. If P be loaded with a weight of 100 pounds, then 1000 pounds would be required upon P′ to counterbalance it.

We have made no allowance in these calculations for the friction of the pistons, which, in making the actual experiment, would be very considerable, but would not affect the principle designed to be illustrated.

155. It will readily be perceived that in the application of the principle above discussed we have the means of producing great pressure by the use of a comparatively small force.

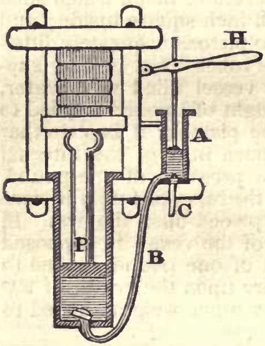

Fig. 70.

This is accomplished in the machine called the *Hydrostatic* or *Hydraulic Press*, figure 70. A is a small cylinder with a solid piston, which is worked by the handle H, and from the lower part of it a strong tube, B, extends to a larger cylinder, in which a strong, heavy piston, P, is fitted so accurately as to move up and down in it without allowing any water to escape by it. C is a tube leading to a cistern of water. Now, if we suppose the diameter of the cylinder A to be 1 inch, and that of the other cylinder 6 inches, the surface of the lower end of the piston P will be 36 times that of the small piston in the cylinder A; and a weight of 1 pound applied on the small piston will produce a pressure upon P, tending to raise it, of 36 pounds. But as the handle H acts as a lever, a man can easily, by means of it, apply a force of several hun-

154. If we suppose the piston O′ to be 10 times as large as O, how many pounds upon P′ will be required to counterbalance 1 pound applied to P? Is any allowance made for the friction of the piston? 155. How is the *Hydraulic Press* constructed? If the smaller cylinder is 1 inch in diameter, and the larger 6 inches, how many pounds applied to the larger piston will 1 pound applied to the smaller counterbalance? If by means of a lever a man

dred pounds, which will be increased, as we have seen, 36 times by the action of the machine. Let us suppose the man, by resting his whole weight upon the handle H, produces a pressure of 400 pounds upon the piston in A, then the piston P will be raised by a force equal to $400 \times 36 = 14400$ pounds.

The power of such a machine may be increased by diminishing the size of the small piston, by increasing the larger piston, or by increasing the length of the handle H. There is, therefore, scarcely any limit to the force it may be made to exert.

156. It is remarkable, that in this machine also, the space passed over by the power will always be to that passed over by the weight, as the weight is to the power. (§ 129.) For, as the large cylinder is 36 times that of the smaller, when the small piston is forced down one inch, the water driven by it into the larger cylinder will fill it up only $\frac{1}{36}$ of an inch, and consequently the larger piston P will be raised only that distance.

157. *Pressure produced by the Weight of Liquids.*—It is to be observed that thus far we have spoken only of pressure which may be applied to a liquid, leaving entirely out of account the weight of the liquid itself, and the pressure resulting from it. This we will now proceed to consider.

It is evident a portion of the liquid in a vessel may be supposed to constitute the piston P, figure 67, for its pressure upon the portion below it will be just the same as if it were solid, and the pressure will be transmitted in the same manner to the bottom and sides of the vessel.

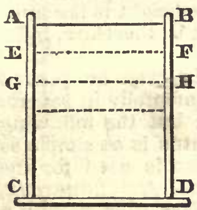

Fig. 71.

158. Let A B C D, figure 71, be a vessel with upright sides filled with water or other liquid. Let us suppose a portion of the liquid A E F B separated from the liquid below by a thin film E F, of some substance; it is plain, as has been remarked, the pressure of the upper portion thus separated from the rest upon the part below, will be the same as if it were solid; for its weight will be sustained by it. Now, let us suppose another portion of the liquid E G H F, equal to the first, is in like manner separated by a film G H, from the part below; it is evident this will exert a pressure equal to that of the first portion; and the whole pressure on the surface G H will be twice as great as that at the surface

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can apply 400 pounds to the smaller piston, how much force will be exerted upon the larger? How may the power of the hydraulic press be increased? 156. What is the proportion between the distance passed over by the power and that passed over by the weight? How does it appear that when the power moves 1 inch, the piston, and of course the weight, will be raised only $\frac{1}{36}$th of an inch? 157. Thus far, have we been speaking of pressure applied to the surface of a liquid, or of the pressure resulting from the weight of the liquid itself? May we consider a portion of the liquid itself as constituting the piston in figure 67? 158. How is figure 71 explained? How does the

EF. If below this we should take a third similar portion of the fluid, the pressure upon the surface on which that would rest would be three times that of the first portion, and so of any other proportion.

It will be seen, therefore, the pressure of the fluid in the vessel increases as we descend exactly in proportion to the depth or distance perpendicularly below the surface.

We have, then, this principle, viz: *the pressure of a liquia at different distances below the surface is always proportional to these distances.*

159. This pressure, it will be observed, at any given point, is nothing more than the weight of the liquid above that point; and of course the heavier the liquid is, the greater will be the pressure, the distance below the surface being supposed the same. The pressure of mercury, therefore, is greater than that of water, and the pressure of water greater than that of alcohol or ether.

It is to be observed too, that though the pressure of liquids increases in proportion to the distance below the surface, still, at any given mathematical point, it will be equal in every direction; that is, at this point, the upward, downward, and lateral pressure, will be precisely the same. But, if we take any appreciable portion of surface, unless it be horizontal, this will not be the case, as the downward pressure will be greatest. But this will shortly be explained more fully.

160. The pressure on the bottom of a vessel filled with a liquid is equal to the weight of a column of the liquid whose base is equal to that of the vessel, and whose height is the same as the depth of the fluid in the vessel. It is, therefore, independent of the shape of the vessel.

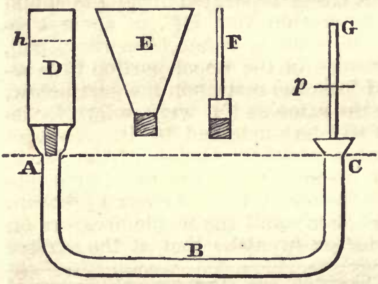

Fig. 72.

This may be proved experimentally in several ways; but the following apparatus is as simple as any that is used for the purpose: A B C, figure 72, is a glass tube, having a brass collar cemented on at A, into which vessels of different shapes, D, E, and F, may be screwed. The tube A B C is filled with mercury up to the dotted line A C, and the

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pressure increase with the depth? How will the pressure of a liquid vary at different distances below the surface? 159. From what does this pressure result? Will the pressure of all liquids be the same at the same depth? Though the pressure increases as we descend below the surface, will it always be the same in every direction at any given point? 160. What is the pressure upon the bottom of a vessel filled with a liquid equal to? Is this pressure independent of the form of the vessel? How may this be

small tube, G, fitted into C, having its lower end extended just to the mercury. The vessel, D, is then screwed on A, and water poured in until it rises to *h*. The surface of the mercury at A will be the base of the column of water, and will of course be forced downward by the weight of the water, and made to rise in G, we will suppose, to the point *p*. If we now unscrew D, and substitute either of the other vessels, E or F, or, indeed, one of any other shape, and fill it with water to *h*, on examining the mercury in the tube, G, it will be found to rise exactly to *p*, proving conclusively that the pressure exerted by fluids is independent of their quantity, and varies only with the perpendicular height, the base being the same in each case. In the case of the funnel-shaped vessel, E, the inclined sides support part of the weight of the fluid; and when the small vessel, F, is used, a part of the downward pressure is counterbalanced by an upward pressure against the sides of the vessel where its diameter is diminished.

161. By availing ourselves of this law, a very powerful force may be exerted by a small quantity of liquid. If, for instance, a cask be filled with water, and a small tube, say $\frac{1}{4}$ of an inch in diameter, and 20 feet long, be closely inserted in the bunghole, and water poured in, the pressure will be sufficient to burst the cask.

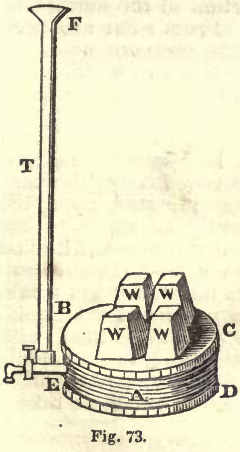

Fig. 73.

The well-known philosophic toy, called the *hydrostatic bellows*, illustrates the same fact; this consists of two flat boards, B C and D E, figure 73, united by leather, A. A short tube communicates with the interior of the bellows, and terminates in a fawcet, by which the water used in the experiment is drawn off. From this short tube a long tube, T, rises perpendicularly, and terminates in a funnel, F. The upper board, B C, is loaded with weights, W, which press it against the lower board, D E; the leather which unites them being collected in folds between them. If now water is poured into the funnel F, it will descend and enter between the boards; and, by continuing the supply, a column will be maintained in the tube, which, by its pressure, will gradually raise the upper board with its load as high as the leather which unites the boards will permit.

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proved by means of the apparatus represented in figure 72? In the case of the funnel-shaped vessel E, how is a part of the weight supported? 161. How may a very powerful force be exerted by a small quantity of water? How is the *hydrostatic bellows* constructed? How are the weights raised

162. In the hydrostatic bellows we see the powerful upward pressure of the column of water within, which is equal to the weight of a column of water having the upper board, B C, for its base, and its height equal to the perpendicular distance from the surface of the water in the tube to the lower surface of the upper board. The pressure of the water in the tube, it will be seen, serves the same purpose as the small piston in the hydraulic press (§ 155); and by increasing sufficiently the length of the tube, any amount of pressure can be produced.

On account of this upward pressure of liquids, if a hole is made in the bottom of a ship, the water rushes in with great force.

163. We have heretofore seen (§ 159) that the pressure of a liquid at any point is the same in every direction, and is proportional to the depth beneath the surface. We have seen, too, that in the case of pressure applied to a liquid, the force exerted on any part of the inside surface will be in proportion to the extent of that surface (§ 151); that is, if we are able to determine the amount of the pressure on one square inch of the surface, it will be twice as much on 2 square inches, three times as much on 3 square inches, &c. So, the upward or downward pressure of a liquid itself on any surface, at any given depth, will be proportional to the extent of the surface, and will be entirely independent of the form of the vessel (§ 160). But the same cannot be said of any portion of the surface of the sides of a vessel filled with liquid. From what has been said above (§ 160), it is evident that the pressure upon the bottom of a vessel, whatever its form, is always just the same as it would be if the sides were upright, and the vessel was all the way of the same diameter as at the bottom.

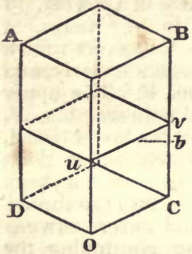

Fig. 74.

Let A B C D, figure 74, be a vessel with upright sides, just a foot square, and two feet high. If this be now filled with water (or other liquid), the pressure upon the bottom would evidently be equal to the weight of the liquid; if we supposed it filled half full to the line *u v*, then the pressure would be only half as much, but still would be just equal to the weight of the liquid. If we now suppose the vessel filled with water, and take a point, as *b*, in the middle of *u v*, the pressure just that point will be equal in every direction; but if we take a

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that are placed on the upper board? 162. What is the upward pressure in the hydrostatic bellows equal to? Why does water rush into a ship when a hole is made in the bottom? 163. Is the pressure of a liquid on the inside of a vessel proportional to the extent of surface? What will be the pressure upon the bottom of a vessel? If it have upright sides, will the pressure of the liquid on its bottom always equal the weight of the liquid? If in the side of the vessel, fig. 74, we take a space equal in extent to the bottom, will the pressure be the same as upon the bottom? What reason can be given? If a cubical vessel be

portion of the surface, as the space $C v u O$, which will be of the same size as the bottom of the vessel, the pressure upon it will not be equal to the whole weight of the liquid, as is the case with the pressure upon the bottom. Nor will the pressure be equal on all parts of the space $C v u O$, for the reason that all parts of it are not equally distant from the surface of the liquid. Near the bottom it is evident the depth beneath the surface of the water will be nearly two feet, while along the line, $u v$, the depth will be only one foot. Between the lines $u v$ and $C O$, the parts would be at different depths, and of course subjected to different pressures.

If a cubical box be filled with water, it is found the pressure on one side is just equal to half that upon the bottom; that is, the pressure is the same as it would be if the side were changed into a horizontal bottom, and half the depth of liquid rested on it. The whole pressure of the liquid in the vessel will therefore be equal to three times its weight.

If the vessel is made twice as high as it is broad, like that represented in figure 74, the pressure against one side would be just equal to the weight of the liquid, and the whole pressure would amount to five times its weight. While, therefore, the pressure of a liquid on the inside of a vessel containing it can never be less than its own weight, it may be increased to any number of times that weight, simply by increasing the height of the vessel.

Fig. 75.

In consequence of the increasing pressure of water as the depth increases, dams and embankments to contain it are always made much thicker at the bottom than at the top, as shown in figure 75.

164. The pressure of liquids at very considerable depths below the surface is enormously great. If an empty bottle tightly corked is sunk by means of weights attached to it to a considerable depth in the sea, the pressure of the surrounding water will either break it by bursting it inward, or it will force the cork into it through the neck, or the water may be forced in through the cork. If the bottle has flat sides, it will be likely to be broken, this form not being conducive to strength.

In one case, a bottle tightly corked, and the cork covered with pitch, was let down into the sea, and on reaching the depth of about 300 feet, an increase of weight was suddenly

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filled with water, how does the pressure upon one side compare with that upon the bottom? What will the whole pressure of the liquid be equal to? If the vessel were made twice as high as it is wide, how would the pressure upon one side compare with that upon the bottom? How may the whole pressure of a given quantity of liquid be increased at pleasure? Why are dams and embankments always made much thicker at bottom than at the top? 164. What is the effect of sinking bottles tightly corked to great depths in the sea? Why is the bottle likely to be broken if it has flat sides? May the water sometimes

felt, which proved to be occasioned by the cork having been forced in, and the bottle of course filled with water. Another bottle was let down in a similar manner, which, on being drawn up, was found filled with water, though the cork remained in its place, the water no doubt having been forced in through the cork or around its sides.

If a piece of wood that easily floats at the surface is let down by means of a weight attached to it to a great depth, the water will be forced into its pores, and increase its weight so much, that it will no longer be capable of floating or rising to the surface.

A diver may descend, with impunity, to a certain depth in the sea, but there is a limit beyond which the pressure cannot be endured; and it is probable that even fishes, though fitted by nature to sustain greater pressures than land animals, cannot exist beyond certain comparatively limited depths. They have, however, in some instances, been caught so far beneath the surface, that they must have sustained a pressure of many tons to every square foot of the surface of their bodies.

165. Liquids being slightly compressible, as we have seen, must become more dense at considerable depths than they are at the surface. According to Mrs. Somerville, (Connection of the Physical Sciences, Section XI.) the density of water is doubled at the depth of 93 miles, and it becomes as dense as mercury at the depth of 362 miles. At greater depths its density of course is still greater.

166. We have seen (§ 149) that the surface of a liquid in a vessel at rest always attains a perfect level; and the same will be true if the liquid is contained in several vessels, provided there is a free communication by means of a tube or otherwise between them. If the vessels be large, and the tube uniting them small, it may require some time; but, in every case, a perfect level in all the vessels will at length be attained.

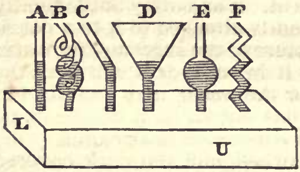

Fig. 76.

Every one's daily observation is perhaps sufficient to satisfy him of this fact; but the following piece of apparatus, figure 76, has been contrived to illustrate it. A, B, C, D, E, F, are several glass vessels of different shapes, connected at the bottom by a flat horizontal tube, L U. Let water be now poured into one of the vessels, and it will be seen to rise in all alike, and stand at the

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be forced in through the cork or by its sides? If a piece of wood is sunk to a considerable depth in water, why will it not rise again to the surface? May divers descend to any depth beneath the surface? Have fishes the power of enduring greater pressure than man can? 165. Are liquids compressible? What then must be the effect upon their density at great depths? 166. Will the surface of a liquid in several vessels communicating together be at the same level in all? How is this shown by figure 76?

same level, notwithstanding the difference in their forms. A teapot, kettle, or other vessel having a spout, to contain a liquid, must have the lip of the spout at least as high as the level of the liquid within; otherwise the liquid will flow out.

167. It is well known that in digging wells in the vicinity of each other, we are not always obliged to penetrate to the same depth in order to find a supply of water; nor is the surface of the water beneath the soil everywhere at the same level, as the principles we have just discussed would seem to require. We sometimes see wells but a few rods apart, both of which perhaps contain water during the year, though the bottom of one of them is scarcely, if at all, lower than the mouth of the other.

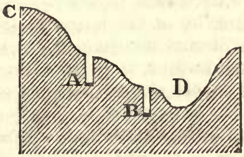

Fig. 77.

Thus, let A and B, figure 77, be two wells dug in the hill side C D; the bottom of A is above the level of the mouth of B, and yet A may be half-filled with water at the same time that it stands much below the mouth of B. But this in reality furnishes no exception to the general law that the surface of a body of water or of several bodies communicating with each other, will be at the same level. The reason why the surface of the water that percolates everywhere through the soil is not at the same level, like the surface of the ocean, may be because of the obstructions that prevent its free passage from place to place, or because of the capillary action (§ 16) of the soil itself. If the earth between the wells A and B is very hard, or composed mostly of clay, which is impervious to water, then the wells may be considered as two separate vessels, in which we should not of course expect the water to be necessarily at the same level. But if the earth at the particular place is of such a nature as to allow the water to pass freely, it may by capillary action be maintained at a higher level at one point than at another.

168. The solution of the *hydrostatic paradox*, as it has been called, will now be easy. As usually stated, it is as follows, viz: "Any quantity of water, however small, may be made to balance any other quantity, however large." To make a very small quantity of water balance a very large quantity, it is necessary only to have two vessels communicating by a tube at the bottom, and of such a form that the small quantity in the small vessel shall stand in it at the same height as the larger

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Quest. 167. Must wells in the vicinity of each other be always dug to the same depth to obtain water? How is this illustrated in figure 77? Does this furnish any exception to the law above given that the surface of a fluid is always level? Why is not the surface of the water contained in the soil level? 168. What is meant by the *hydrostatic paradox?* How may a small quantity of a liquid be made to balance a much larger quantity? Suppose it

quantity in the large vessel. Suppose it were required to make a cubic inch of water sustain or balance a cubic foot, or 1728 cubic inches.

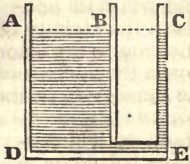

Fig. 78.

Let ABD and CE, figure 78, be two cylindrical vessels standing side by side, and communicating with each other by a small tube; and let the diameter of the first be such that the upper surface of the water in it shall be 1728 times the surface of the liquid in the other, and the object will be accomplished. For if the two vessels are cylindrical, the bottom or section of one being 1728 times that of the other, it is evident that whatever may be the height of the water in one, it must be at the same height in the other. If it is required that a still smaller quantity than a single cubic inch shall balance the cubic foot, it is necessary only that the diameter of the smaller vessel should be proportionally diminished.

169. The methods adopted for conducting water in canals through a country depend on the above property, by which liquids find their own level. When the space through which a canal is to be conducted is a uniform plain, there is of course no difficulty; but when the surface is uneven, *locks* are required, which are large reservoirs capable of containing the boats that navigate the canal, and having large gates at each end, so that they may be filled and emptied at pleasure. When a boat is to ascend, the lower gate is opened, and the lock or reservoir emptied, so that the water in it stands on a level with that in the canal below, while the upper gate prevents the water entering from the canal above. As soon as the boat enters the lock, the lower gate is closed, and the upper one opened; and, the water from above entering, soon fills it to a level with that in the canal above, the boat of course rising with it, ready to proceed on her way.

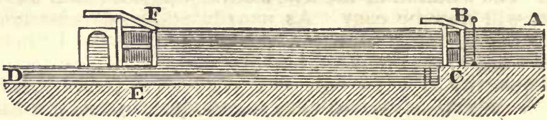

Fig. 79.

Thus, let AB and CD, figure 79, be two adjacent levels on a canal; BC and FE two floodgates, that may be opened and closed at pleasure. Now, suppose a boat coming up the canal

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was required to make a cubic inch of water balance or counterpoise a cubic foot, what would be necessary? 169. What are *locks* in canals? Are they used in a level country? How does a boat ascend through a lock? How does the boat descend?

at D is to pass through the lock; the gate, F E, is opened, and the boat allowed to pass in, when it is again closed, and the water let in through small gateways in the large floodgates B C, by which the space between the two large gates, called the lock, is soon filled, and the boat raised to the level of the water, B A. The floodgate, B C, is then opened, and the boat passes onward. It is evident the space between the floodgates, or the length of the lock, cannot be less than the length of the boats made to pass it.

The method by which a boat is made to pass downward through a lock will now be understood without a particular description.

170. When water is conveyed a distance for the purpose of supplying a town, it is sometimes conducted in a canal, which may be covered (as is the Croton aqueduct in New York) or open; but often close pipes are used, which are made strong to endure great pressure, and laid a little below the surface, without reference to its unevenness. But it is to be noticed that the pipes must at no place rise higher than the source from which the water proceeds. In this way water may be conveyed even to the upper stories of houses, provided the source is sufficiently elevated.

171. In many mechanical operations it is necessary to have some convenient means for finding a true level, or horizontal line.

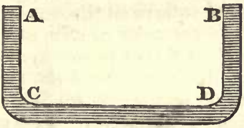

Fig. 80.

For this purpose a vessel of water of such a form that the surface may be considerably extended, as a large basin, will answer in many cases; but a tube bent in the form A C D B, figure 80, filled with water, is better. If the parts A C and B D are of the same length, when it is perfectly horizontal, water upon being poured in will rise exactly to the edge at both ends of the tube.

To determine whether a beam, or floor, or other object is horizontal, the workman has only to place the instrument upon it, in the position shown in the figure, and fill it with water. If the water does not rise exactly to the edge at both extremities, he of course knows that the object is not in the true horizontal position. If he wishes to determine which of two objects at a distance from each other is highest, he places it upon one of them in a horizontal position, and sights across the ends of the tube.

The above explanation exhibits the principle of the instru-

Quest. 170. What is an aqueduct? May an aqueduct be open like a canal, or closed? When close pipes are used, why may not the aqueduct be carried to any place higher than the fountain? 171. How may a level be found by means of a basin of water? How by means of a bent tube?

ment, but other fixtures are usually added to it to render it more convenient for use.

172. But another instrument, called a *spirit level*, from its compactness and little liability to injury, is now generally used by mechanics. It consists of a cylindrical glass tube, slightly curved, and filled with alcohol, except a small space which contains air, and is sealed by closing up the glass at each end. In whatever position it is placed, the air will be uppermost; and if the extremities are at the same level, it will be in the middle, this being the highest point.

Fig. 81.

If the tube is not exactly level, the bubble will incline towards the highest end. Figure 81 represents the tube inclosed in a brass case, A B, in a horizontal position, with the air-bubble in the centre. The tube is usually inclosed in brass, except a small part of the upper side.

173. *Immersion of Solids in Liquids.*—When a solid is immersed in a liquid, it is evident that a portion of the liquid, equal in bulk to that of the solid, must be displaced, else it would be possible for two bodies to occupy the same space at the same time. This is shown very easily by experiment as follows:

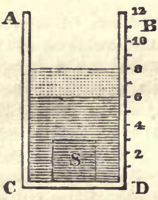

Fig. 82.

Let A B C D, figure 82, be a vessel with perpendicular sides, 6 inches square at the bottom, and a foot high, partly filled with water, as to the figure 6. As it is just 6 inches square at the bottom, every inch in height will contain just 36 cubic inches of water; 2 inches in height, 72 cubic inches; and so on. Let us suppose, now, a block of marble, or other heavy substance, S, precisely 4 inches square, is dropped into it; a portion of the water will be displaced or moved to another part of the vessel, as will be manifested by the rise of the surface nearly to the figure 8, just as if so much more liquid had been poured in. The block, S, being 4 inches square, would contain just 64 cubic inches; and upon measurement after its immersion in the water, the surface will be found to have risen $1\frac{7}{9}$ inches; showing that just 64 cubic inches of water had been displaced, for $36\times1\frac{7}{9}=64$.

Quest. 172. How is the *spirit level* constructed? How does it show when a true level or horizontal position is obtained? 173. When a solid is totally immersed in a liquid, what quantity of the liquid must be displaced? How is this illustrated by figure 82? If the vessel is 6 inches square, and a cubical block 4 inches on each side be dropped into it, how high will the water be made to rise?

174. It will be seen that we have here an excellent method to determine exactly the bulk or solid contents of an irregular mass of any solid not soluble in water; for, whatever be the form of the mass, it will always displace a volume of water just equal to itself; and, by observing the rise of the surface, the additional part of the vessel so filled can be at once calculated as just shown. If, for instance, an irregular mass should cause the water in the above vessel to rise just 2 inches, we should know that it must contain 72 cubic inches; and so of any other height.

An ingenious practical use is sometimes made of this property of liquids by blacksmiths, in certain cases in which it is necessary to use a given weight of iron. In the construction of gun-barrels for government, it is required that, when finished, they should have a prescribed weight; and in order to this, to prevent great waste, it is necessary for the workman to commence with a proper quantity of iron. The iron is procured in bars, which, however, vary a little in size, else it would be sufficient to measure the same length of the bar for each barrel. To determine the proper length, whatever may be the size of the bar, the workman proceeds in the following manner:

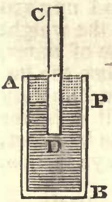

Fig. 83.

He first procures a tub of the proper capacity, as A B, figure 83, and fills it with water to a point, P, which is to be ascertained by trial. He then immerses one end of the bar, C D, perpendicularly, until the water rises so as just to fill the tub, and marks on the bar the line to which it is wet; the part immersed will then be just sufficient for his purpose. This method supposes, as will be seen more fully hereafter, that all the iron used is of equal density.

175. When a solid is immersed in a liquid, it presses downward with a force equal to its own weight; and, as we have seen, when wholly immersed, displaces a quantity of the liquid equal in volume to itself. If this quantity of the liquid is lighter than the solid, the latter will sink, but if heavier it will swim. If the two are precisely of the same weight, the solid will remain suspended in the liquid, in whatever position it may be placed. When a body is immersed in a liquid heavier than

Quest. 174. How may we determine the solid contents of an irregular mass? Suppose an irregular mass should cause the water in the above vessel to rise two inches when immersed in it, what must be its solid contents? How is the result obtained? How does the blacksmith determine the quantity of iron to be cut from a bar, in the manufacture of certain articles, as gun-barrels? Does this method suppose all the iron to be of the same density? 175. When a solid is immersed in a liquid, with what force does it press downward? When wholly immersed, how much fluid is displaced? When will the body sink, and when will it swim? When a body is im-

itself, it will sink until it displaces a quantity of the liquid just equal in weight with itself.

176. The reason of the above statements may perhaps be made plainer by further illustrations.

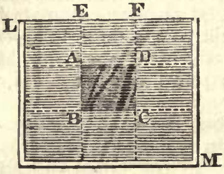

Fig. 84.

Let L M, figure 84, be a vessel filled with water, containing a cubic block, A B C D, immersed in it, which, for the present, we will suppose to have the same weight as an equal bulk of water. It is evident it will remain exactly in this state of rest unless disturbed. On the upper side it sustains the pressure of the column of water, E A D F, which we will suppose just a cubic foot also; and on the lower surface, B C, it will sustain an upward pressure of twice this amount, since the depth beneath the surface is here 2 feet. But to the downward pressure of one cubic foot of water is to be added its own weight of one cubic foot, making it just equal to the upward pressure. It will therefore remain at rest.

177. But let us now suppose the mass, A B C D, is heavier than an equal volume of water; the downward and upward pressure of the water will be the same as before; but the weight of the solid being greater than that of an equal volume of water, it will tend to sink by the difference. Again, suppose the immersed body to be lighter than water, bulk for bulk, it is easy to see that the solid will tend to rise by as much as it is lighter than an equal volume of water. When a body floats in water, the absolute weight of the water displaced will always be just equal to the whole weight of the body.

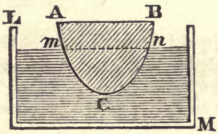

Fig. 85.

Let L M, figure 85, be a cistern of water, and A B C, a body floating in it; then the weight of the water displaced by *m n* C will always be just equal to the whole weight of the body, A B C. For, if the weight of the water displaced were less than that of the body, it would sink lower, and displace a greater quantity of the fluid; and if the weight of the water were greater than that of the body, the upward pressure of the surrounding water would be greater than the downward pressure of the

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mersed in a liquid heavier than itself, to what depth will it sink? 176. If in figure 84, the block A B C D is of the same weight as an equal volume of water, what will be the effect? How is it shown that it would remain at rest beneath the surface? How much greater is the upward than the downward pressure? Why then will not the block rise to the surface? 177. If the block were heavier than an equal volume of water, what would be the effect? If lighter, what would be the result? When a body floats in water, how will the weight of the water displaced compare with the weight of the body? If a

body, and it would rise; coming to a state of rest in either case, when the weight of the displaced fluid is just equal to the weight of the body.

As a matter of course, if the above principles are correct, no solid can float on the surface of a liquid, if it be heavier than its own bulk of the liquid; but, as the bulk of most or all substances can be increased without increasing their weight, it may be formed, however heavy, so as to float. Thus, vessels made of brass, iron, and other heavy substances, readily float upon the surface of water, as every one knows. So iron steam-vessels are not now uncommon. In consequence of their form, they displace just as much water as if they were solid; but their weight is very much less. If they are filled with water, therefore, they immediately sink.

178. The effect of immersing a body in a liquid is always to lessen its apparent weight, as every one has noticed who has attempted to lift a stone or other heavy substance in water. In the water it is perhaps raised without difficulty; but on coming to the surface, a great and sudden increase of weight is observed. So every one who, while bathing, has walked in the water, has observed how lightly he presses upon his feet. If the depth is considerable, and the body is immersed to the shoulders, the person seems to himself to have little or no weight; and, if there is even a moderate current, he finds himself in danger of being washed away, in consequence of the very insecure hold his feet have upon the bottom.

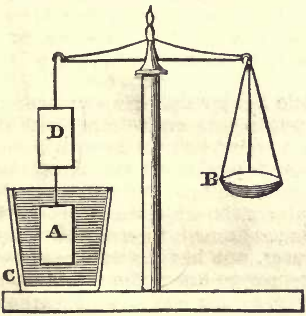

Fig. 86.

179. This loss of weight by a body when immersed in a liquid, as may be inferred from what has been already stated, is always just equal to the weight of the liquid displaced by it. An easy method of proving this important principle is as follows. Let C, figure 86, be a vessel which we will at first suppose empty, and let A be a cylindrical mass of some solid capable of sinking in water, and turned very accurately so as just to fit inside the cylindrical vessel, D.

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substance heavier than water, bulk for bulk, will sink, how are vessels of iron made to float in water? 178. Why does a body, when immersed in water, appear to be lighter than in the air? Why is it that a person wading in deep water seems to himself to be so light? Why is he in danger of being swept away if there is a current? 179. What is the loss of weight of a heavy body, when immersed in a liquid, equal to? How is this proved by the use of the apparatus represented in figure 86?

Now let the body, A, be suspended by a fine thread to the vessel, D, and an exact equipoise produced by placing weights in the scale-pan, B. Upon pouring water in the vessel, C, the scale-pan B will preponderate; but the equipoise will be again restored by filling the cylindrical vessel D with water. Now, as the cylindrical vessel D is of such a size that the solid mass A will exactly fit into its interior, it follows that the water with which D is filled is precisely equal in bulk to the solid A; proving that the apparent loss of weight suffered by A on being immersed in water, is just equal to the weight of a mass of water equal in bulk to itself.

180. If a body lighter than water be first sunk by means of weights, and then these weights removed, it will rise with more or less force, depending upon its mass and its weight compared with that of water. Many contrivances on this principle have been suggested for raising sunken vessels, and for lifting vessels over shoals when loaded too deeply to pass without assistance. A machine of this kind, called a *Camel*, in use in several places in Europe, consists of two immense boxes, which are made water-tight, and filled with water, and then lashed strongly one to each side of the vessel, below the surface of the water. The water within is then pumped out, and their buoyancy is sufficient often to raise the ship several feet.

181. *Life-preservers* are constructed on the same principle. They are made of some flexible substance, as India rubber cloth, and of such a form as usually to encircle the waist, and be easily attached to the body. In case of danger, they are readily inflated by a mouth-piece and valve provided for the purpose, and are then so light and buoyant that the person is in no danger of sinking. *Life-boats* are also constructed on this principle.

182. The human body is a little lighter than its own volume of water, and of course ought not to sink entirely beneath the surface. Usually, it is found that about half the head will float above the surface; and with presence of mind and the proper exertion of the hands and feet, the swimmer finds no difficulty in keeping his mouth and nose above the water so as to breathe freely. But when persons unaccustomed to swimming are accidentally thrown into the water, not having sufficient presence of mind, or not knowing how to move the limbs, so as to bring the head to the surface, in the effort to breathe, a

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Quest. 180. What will be the effect if a body lighter than the same volume of water be sunk by means of weights, and the weights afterwards removed? What is the design of the machine called the *camel*? How is it constructed? 181. How are *life-preservers* constructed? How are they inflated? 182. Is the human body lighter or heavier than water, bulk for bulk? May a good swimmer easily keep his mouth and nose above the water? Why is it that

quantity of water is drawn into the lungs, by which the weight of the body is so increased that it becomes a little heavier than an equal bulk or volume of water, and of course sinks to the bottom; there it remains, until, by its decomposition, the gases that are formed cause it to expand so much, that it displaces more water than is equal to its own weight, and it thus rises.

The bodies of fishes are very nearly of the same weight as an equal bulk of water; but they are also furnished with an air-bladder, by means of which they are able to change the bulk of their bodies, and therefore rise or fall at pleasure. The air-bladder is usually attached to the spine or back-bone, and consists of a strong muscular sack which is partly filled with compressed air. When the fish wishes to descend, the muscles of this sack are tightly drawn, and the air within still more compressed, and its volume diminished; but, when he wishes to rise, these muscles are relaxed, and the air within expands, increasing the bulk of the animal.

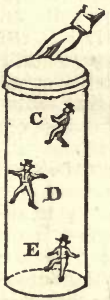

Fig. 87.

183. An amusing toy is sometimes seen, which consists of a glass jar nearly filled with water, and having several glass images (C, D and E, figure 87) floating in it. Over the top is tied very closely a piece of bladder or leather; and when it is slightly pressed with the hand, the images are seen gradually to sink to the bottom, but rise again as soon as the pressure is removed. The images are made hollow, and contain just sufficient air to make them swim under the ordinary pressure of the atmosphere; but, when the pressure is increased by placing the hand upon the leather covering of the jar, the volume of air therein is diminished, and water forced in through little holes in the feet. Their weight is then so increased that they sink; but, on the removal of the pressure, the air within expands, and forces out a portion of water, and the image again rises.

184. When a body is designed to float in a liquid, it is as necessary that regard should be paid to the proper support of its centre of gravity (§ 42) as if it were intended to stand permanently upon a plain, otherwise it will not remain in its proper

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persons unaccustomed to swimming almost always sink in a short time when accidentally falling into the water? What is said of the weight of the bodies of fishes as compared with water? By what means do they manage to rise and fall at pleasure? 183. How are the little images in the vessel of water, represented in figure 87, made to rise and fall in the water? How is it explained? 184. Must the centre of gravity of a body floating in a liquid be

position in the liquid, or will be in danger of being capsized. But the various circumstances upon which the stable equilibrium of a body floating in a liquid depends, cannot be here investigated.

185. All that has been said respecting the ascent and descent of solids in liquids applies equally to two or more liquids in the same vessel. If the liquids are incapable of acting in any manner upon each other, they will arrange themselves in the vessels, in the order of their weights, the lighter above the heavier. Thus, oil always floats upon the surface of water, but sinks in alcohol. If a bottle with a small neck be filled with water, and the mouth inverted in a vessel of alcohol, the water will be seen to form a descending current through the neck, while the alcohol, being the lighter of the two, will gradually rise and take its place.

Thus, a sailor on board of a vessel loaded in part with brandy, wishing a little of "the ardent," filled a junk bottle with water, and holding the mouth with his hand, suddenly inverted it in the bunghole of a cask, filled with the spirit. After holding it there some time, he quickly removed it, and found it filled with a mixture of brandy and water, just suited to his taste. On having his honesty called in question, he declared he had done no injury to any one, as he left the cask as full as he found it! The student will perceive, that though culpable in morals, his principles of philosophy were correct.

186. Water, when heated, expands, and therefore becomes specifically lighter, and as a necessary consequence rises to the surface. Hence, a vessel of water may be gradually heated merely by having a tube extend from it to the fire, though it be at a considerable distance. The water in the tube is first heated, and ascends to the boiler or vessel to which the tube is connected; and, at the same time, the cold water in the vessel descends in the tube, and is in its turn also heated. The apparatus answers better if there are two tubes, in one of which the cold water will descend, and the warm water ascend in the other.

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supported? 185. If two liquids, incapable of mixing with each other, are poured into a vessel, how will they arrange themselves? Which is the heavier, water or alcohol? Why does oil always float upon the surface of water? If a person should fill a bottle with water, and then invert it, holding the mouth in alcohol, what would be the result? How did the sailor obtain a quantity of brandy from a cask without diminishing the quantity of liquid in the cask? How is the fact to be explained? 186. Why does water become lighter when heated? How may a vessel of water be heated by means of the piece of apparatus represented in figure 88?

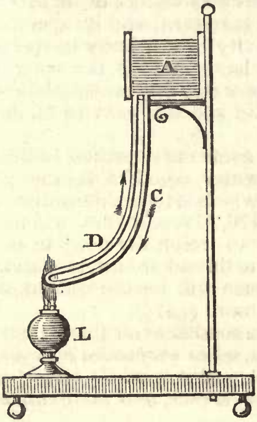

Fig. 88.

Let A, figure 88, be a vessel of water supported upon a stand two or more feet high, and let C D be a tube extending from the vessel, A, to the flame of the lamp, L, and then doubling and returning, the two ends being carefully soldered into the bottom of A. By the lamp, a portion of the water in the tube is heated, and rises in the part, D, a current of cold water at the same time descending in C, as shown by the arrows. In this way a cistern of water in the third or fourth story of a building is often kept heated by means of tubes extending from it to the fire in the kitchen in the first story.

187. *Specific Gravity.*—By the specific gravity of a body is meant its weight when compared with water, which is adopted for the standard. When, therefore, we say of any substance, that its specific gravity is 2 or 5, we mean that, bulk for bulk, that substance is twice or five times as heavy as water. Thus, the specific gravity of sulphur is 2; since, therefore, a cubic foot of water weighs $62\frac{1}{2}$ pounds, a cubic foot of sulphur would weigh twice as much, or 125 pounds. When we say the specific gravity of gold is a little more than 19, we mean that if equal bulks are taken, the gold will weigh a little more than 19 times as much as the water.

Water has been agreed upon as the standard of comparison for two principal reasons, viz. 1st. In common with other liquids, it is much more convenient for use than a solid would be; and 2d. It is more easily and cheaply obtained than any other liquid.

188. To determine the specific gravity of a body, all that is wanted besides its own weight is the weight of a quantity of pure water of precisely equal bulk with itself. Thus, if the bulk of the body is just a cubic inch, and it weighs 504 grains, and we know the weight of this bulk of water to be 252

Quest. 187. What is meant by the specific gravity of a body? What is meant when we say the specific gravity of a body is 2 or 5? What is the weight of a cubic foot of water? What then must a cubic foot of sulphur weigh, the specific gravity of which is 2? How is this found? Why is water taken as the standard of specific gravity? 188. What are wanted in order to determine the specific gravity of a body? Having the weight of a

grains, it is of course just twice as heavy as water; or, in other words, water being assumed as our standard, and its specific gravity called 1, then the specific gravity of the body in question is 2. Here, it will be seen, we have divided the weight of a given bulk of a substance by the weight of an equal bulk of water, and the quotient we call the specific gravity of the body.

189. It remains then only to devise some easy method to find readily the weight of a quantity of water equal in volume to any substance, the specific gravity of which is to be determined; and this, after what has been said (§ 176, 179, and 180), will not be difficult. It will only be necessary to weigh the body in the air, and then, when suspended by a fine thread or hair, in water; and the loss of weight in the latter case will be the weight of a quantity of water equal to itself in bulk. (§ 178).

190. To find the specific gravity of a solid heavier than water, then, *first weigh it in the air, and then, when suspended by a fine thread in water, subtract its weight in water from its weight in the air, and divide the latter by the difference, and the quotient will be the specific gravity required.*

Suppose a piece of copper to weigh in air 204.7 grains, and in water 181.7; subtracting the latter number from the former, we have 23 grains for its loss when weighed in water. Then dividing 204.7 by 23, we have 8.9, which is the specific gravity of the copper.

191. If the body is so light as to swim in water, this method must be modified a little; but the details cannot be given here. So also if the substance, the specific gravity of which is to be determined, is in the state of powder, or is soluble in water, as common salt or alum, other modifications of the method described above must be devised, which are fully pointed out in larger works on this subject.

A balance prepared for determining the specific gravity of bodies, as above described, is called a *hydrostatic balance.* It differs from a common balance only in having the scale-pans suspended a little higher from the table to admit of small vessels of water being placed underneath, and also in having hooks attached to the under side of the scale-pans, to which small substances may be suspended by means of a thread or horsehair.

That the results may be accurate, it is always necessary that

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body, and also the weight of an equal bulk of water, how is the specific gravity of the body obtained? 189. Having a solid body, how may we determine the weight of a quantity of water equal to it in volume? 190. What is the rule given for finding the specific gravity of a solid? If a piece of copper weighs in the air 204.7 grains, and in water 181.7 grains, what will be its specific gravity? 191. What is the *hydrostatic balance*? Must the water be pure that is used in taking specific gravities?

the water used in these operations should be perfectly pure, and also of the proper temperature, which is usually supposed to be 60° Fahrenheit.

192. The specific gravity of a liquid may be readily determined in several ways, one or two of which will be mentioned. Let a phial with a small mouth be accurately balanced with weights, and then filled with pure water, and its weight ascertained. Then fill it with the liquid under examination, and again weigh it; and divide the weight of the latter liquid by the weight of the water, and the quotient will be the specific gravity of the liquid as required.

Suppose a bottle to be first accurately balanced in the scales by a weight, and then when filled with water to weigh 625 grains, but when emptied and again filled with diluted sulphuric acid, to weigh 1000 grains; it is plain we have by this means the weight of equal volumes of the two liquids, and to obtain the specific gravity of the acid we have only to divide its weight (1000 grains) by the weight of the water (625 grains.) Thus, $1000 \div 625 = 1.6$, which is the specific gravity of the acid. In like manner, if, when emptied and again filled with alcohol, it should be found to weigh 537.5 grains; then, $537.5 \div 625 = 0.860$, which is the specific gravity of the alcohol. If the bottle were made of such a size that it would hold precisely 1000 grains of water, then the weight of any other liquid contained in it when filled, divided by 1000, would be the specific gravity of that liquid. Thus, if such a bottle would hold 1600 grains of diluted sulphuric acid, then its specific gravity would be $1600 \div 1000 = 1.6$. (*See Author's Chemistry*, page 113.)

193. An instrument called a *hydrometer* is also used for this purpose. We have seen (§ 179) that when a body is immersed in a liquid heavier than itself, it sinks until it displaces a quantity of the liquid equal to itself in weight. The same solid, therefore, must sink deeper in liquids that are light than in those that are heavier; and by having the solid of a convenient form and properly marked, in accordance with the results of previous trials, the depth to which it sinks in any liquid may be made to indicate with considerable accuracy the specific gravity of that liquid.

Quest. 192. What is the first method mentioned for finding the specific gravity of a liquid? If the bottle were made so as to hold just 1000 grains of water, what only would be necessary in obtaining the specific gravity of a liquid? 193. What is the design of the *hydrometer?* How is it used? Why does it sink deeper in a light liquid than in a heavy one? How is the hydrometer constructed? Why is it loaded with mercury or shot? How is the specific gravity of a liquid shown by the hydrometer? If two columns of liquids of different specific gravities are made to balance each other in the upright parts of a tube bent in the form represented in figure 90, what will

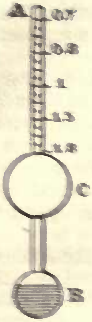

Fig. 89.

The hydrometer may be made of metal, but is usually glass. Its usual form is seen in figure 89. C is a bulb filled with air to make it buoyant, while the bulb B is nearly filled with shot or mercury to make it take the proper position when immersed in a liquid. The stem, A, is a glass tube, containing in it a piece of paper fixed to the glass by a piece of sealing-wax or other substance, and having marked upon it the points, determined by previous trial, to which the instrument will sink in liquids of particular specific gravities. The marks may be made upon the stem A itself, and thus the paper be dispensed with. Sometimes, instead of the graduated stem, weights are used which are so constructed as to be readily attached to the instrument. The weight required to sink the instrument to a given fixed point in this case indicates the specific gravity of the liquid under examination.

The above description is designed merely to illustrate the principle on which the instrument is constructed; the scales are often differently graduated. In the instrument figured in the margin, the specific gravities are directly marked upon the scale. Thus, when the instrument sinks in a liquid to 1, this is its specific gravity; in liquids of the specific gravity 1.5, 1.8, or 0.7, it will sink to these points respectively.

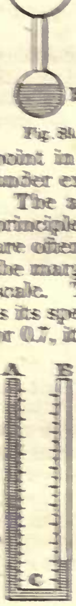

Fig. 90.

The different specific gravities of two liquids may be very satisfactorily shown by balancing them against each other in a bent tube. Let ABC, figure 90, be a bent tube of rather small bore, having the two upright parts carefully graduated to tenths of an inch; then let the horizontal part, C, be filled with the heavier of the two liquids which are to be compared, and which must be supposed of such a nature as not readily to mix; as, for instance, water and mercury, or water and oil. We will suppose water and mercury are the two liquids to be compared; after filling very accurately the part C with mercury, water is to be poured into one end of the tube, and mercury into the other, care being taken all the time to keep the horizontal part of the tube just filled with mercury, and not allowing it to rise in the part containing the water, or the water to stand in the horizontal part C. If this precaution is observed, it will make no difference how high the perpendicular parts of the tube are filled; but it will always be found that the perpendicular co-

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be their comparative lengths? If mercury and water are used, what will be the length of the column of water when that of mercury is 2 inches? What is the explanation?

lumn of water will be $13\frac{1}{2}$ times that of the mercurial column, for the reason that mercury is $13\frac{1}{2}$ times heavier than water. If the column of mercury is 2 inches in height, the column of water to balance it must be 27 inches, and in the same proportion for any other height. If water and oil were used—an oil, for instance, of the specific gravity 0.8—then, observing the same precautions as before, when the column of water is 8 inches in height, that of the oil will be 10 inches; and so of any other height.

194. It is often desirable, when we know the specific gravity of a body, to be able to find from this the absolute weight of a given mass of it, as a cubic inch or cubic foot. This is done by multiplying the weight of a cubic inch or foot of water by the specific gravity of the substance in question. (§ 181.) A cubic inch of water at 60° Fahr. weighs $252\frac{1}{2}$ grains; the weight of a cubic inch of sulphur, therefore, the specific gravity of which is 2, will be found by multiplying $252\frac{1}{2}$ by 2, which will give as the product 505. The weight of a cubic inch of sulphur is then 505 grains. The weight of a cubic foot of water at 60° Fahr. is just 1000 ounces avoirdupois, or $62\frac{1}{2}$ pounds. The specific gravity of platinum being about 21.47ths, the weight of a cubic foot of this metal is ($21.47 \times 1000 = 21470$) 21470 avoirdupois ounces, or 1342 pounds nearly.

195. It will be recollected we have in our remarks considered the specific gravity of water to be unity, or 1; in many works this is taken at 1000; but this is of little consequence, as to change the numbers we have given into what would be required on this supposition, it is necessary only to multiply them by 1000, or, which is the same thing, remove the decimal point three places to the right. Thus, the specific gravity of platinum, water being 1000, will be 21470, instead of 21.47, as given above.

By means of the specific gravity of bodies their state of purity may often be determined, and adulterations detected which are so frequently made with the design to defraud. Thus, gold may be alloyed with a mixture of copper and silver, so as to form a compound that will resemble the pure metal almost perfectly in most of its properties except the specific gravity, which of course would be too low. So, milk, and oil, and spirits of every kind, are constantly more or less adulterated, and the

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Quest. 194. If we know the specific gravity of a body, how may we determine the weight of a cubic foot or a cubic inch? The specific gravity of platinum being 21.47, and a cubic foot of water weighing 1000 ounces, or $62\frac{1}{2}$ pounds, what will be the weight of a cubic foot of platinum? 195. What have we considered the specific gravity of water? If the specific gravity of water is taken at 1000, what change only is necessary in the numbers given? May we often determine whether a substance is pure or not by means of its specific gravity? How is this illustrated by reference to gold? What is a

mixture sold for the pure article; but, by testing the specific gravity, the imposition can usually be detected. The *lactometer*, for determining the purity of milk, and the *oleometer*, for ascertaining the purity of oil, are only modifications of the hydrometer (§ 193) to adapt them to their specific purposes.

196. The specific gravity of a gas may be determined in the same manner as described above (§ 192) for obtaining that of a liquid; but, in consequence of the extreme lightness of these substances, atmospheric air is usually assumed as the standard to which they are referred, in order to avoid the fractions that would otherwise embarrass our operations. Let a flask of suitable size be provided with a good faucet and then weighed, first when filled with air, and then after being exhausted of air by means of the air-pump. The difference will show the weight of the air it contained. Then, let it be filled with the gas in question, and again weighed, and from this subtract the weight of the flask, and we have the weight of the gas that was in it. Divide this last by the weight of the air first obtained, and the quotient will be the specific gravity of the gas, as required. Let us suppose we have a flask fitted with a suitable faucet, which will contain just 28 grains of atmospheric air, but only 27 grains of nitrogen gas. Then, $27 \div 28 = .964$, which is nearly the proper specific gravity of this substance. (*For further remarks on this subject, see Author's Chemistry*, page 113.)

197. *Motions of Liquids.*—This branch of Hydrostatics, which treats of liquids in motion, has sometimes been called *Hydraulics*, in contradistinction from *Hydro-dynamics*, which treats only of the laws which prevail in liquids when at rest.

198. When a small hole is made in the side of a vessel filled with a liquid, a stream is seen to issue from it with more or less velocity, depending upon circumstances which are now to be noticed. The force that puts the liquid in motion must, before the orifice was made, have caused a constant pressure against the portion of the vessel removed; in other words, it is the general pressure of the liquid. This pressure we know to be proportional to the perpendicular depth below the surface of the liquid (§ 158); and we may here infer that the lower the orifice is below the level of the liquid, the greater will be the violence with which the liquid will issue.

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lactometer? What is an *oleometer?* 196. What is made the standard of specific gravity for the gases? Will a flask weigh less when exhausted than when filled with air? How is the specific gravity of a gas found? If a flask is capable of holding 28 grains of air, but only 27 grains of nitrogen, what must be the specific gravity of this gas? 197. Of what does the branch of science called *Hydraulics* treat? 198. Why does the water rush from a vessel filled with water when a hole is made in the side? Must there have been a constant pressure against the part before the hole was made? To what is this pressure proportional?

199. It is found by experiment that the quantities of liquid which escape from orifices of the same size at different depths, other things being the same, are as the square roots of these depths.

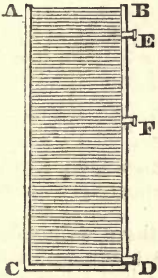
Fig. 91.

Thus, let A B C D, figure 91, be a vessel with perpendicular sides, filled with water, having orifices of the same size at E, one foot below the surface; at F, four feet; and D, nine feet below the surface; and let it be supposed that the vessel is all the time kept quite full by pouring in water at the top as it issues from the orifices below. Then, it is found by accurate experiment, that, in a given time, as a minute, twice as much water will escape at F as at E; and at D, three times as much. But 2 is the square root of 4, and 3 the square root of 9; therefore, as above stated, the quantities of water discharged at the different orifices are as the square roots of the distances respectively beneath the surface. Now, as the orifices are all of the same size, it is plain that the velocities of the several streams must be exactly proportional to the quantities of water issuing in a given time. Thus, the velocity of the stream from F will be twice that of the stream from E, &c. To obtain a fourfold quantity of water, and therefore a fourfold velocity, the orifice would have to be made 16 feet below the surface; and to produce a fivefold velocity, it must be 25 feet beneath the surface, and so on.

It has been heretofore seen (§ 78) that when a heavy body falls a given distance, as a foot in a second, it always acquires at the end of the time a velocity of 2 feet a second; and if it continue to fall 2 seconds, it will pass through 4 feet, and acquire a velocity of 4 feet a second. At the end of another second, it would be 9 feet from its starting point, and would have a velocity of 6 feet a second; and so on.

It appears, then, that a heavy body in falling a given distance, as a foot, acquires a certain velocity; and that in order to double this velocity, it must fall 4 times the first distance, or 4 feet; and to triple its velocity, it must fall 9 times the first distance, or 9 feet.

Quest. 199. If several orifices are made at different depths, what will be the proportion of the several quantities of water discharged from them? If these orifices are made at the depth of 1, 4, and 9 feet beneath the surface, what will be the relative quantities of water discharged? As the orifices are of the same size, must the velocity of the several currents be in the same ratio as the quantities discharged? To obtain a fourfold velocity, what must the depth be? What to obtain a fivefold velocity? If a heavy body should fall a foot in a second, what will be its final velocity? How far must it fall to acquire twice this velocity? How far to acquire six times the velocity it had at the end of the first second? Will the velocity with which a liquid issues from an

It will therefore be evident that the velocity with which a liquid issues from an orifice will be the same as a heavy body would acquire in falling the distance from the surface of the liquid to the orifice.

If two vessels precisely alike, with similar orifices at the bottom, are filled with water, and one is allowed to empty itself, but the other kept constantly full by the addition of fresh fluid, when the water is all discharged from the former, it will be found that just twice as much has escaped from the latter as from the former.

This, it will be perceived, is a necessary result from the principles above developed, in connection with the law that a falling body in any given time traverses just half the distance it would pass through in the same time, if moving uniformly with its final velocity. (§ 77.)

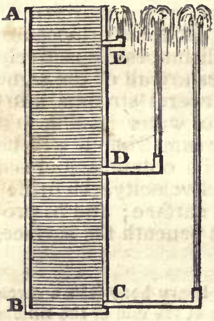

Fig. 92.

200. It follows from these principles also, that if an orifice is made upward, the issuing jet should rise just as high as the surface; since a body projected perpendicularly upward will rise precisely to the same height as the distance it would have fallen by the force of gravity in the same time. Let A B, figure 92, be a cistern of water, with tubes at different distances beneath the surface, having their mouths bent upward, as E, D, and C; then the jets issuing from them should rise just to the surface of the water. But this is found not to be precisely the case when the experiment is made, as the liquid is considerably retarded by friction against the sides of the orifice, and by the resistance of the air.

201. The jet of 7 inches diameter from the inverted syphon through which the water of the Croton aqueduct at present crosses under Harlem River, 9 miles from the city of New York, affords probably as good an opportunity to make the experiment on a large scale as there is in the world. The orifice, according to Mr. Tower, is 120 feet below the surface of the water in the aqueduct on the bank of the river above; but the water rises in the jet only about 115 feet.

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orifice be equal to that a heavy body would acquire in falling from the surface to the orifice? 200. If an orifice open upward, how high should the jet rise? How is figure 92 to be explained? Why will not the water rise as high as the surface of the reservoir? 201. In the jet from the inverted syphon connected with the Croton aqueduct, how high does the water rise? What is the height of the water above the orifice?

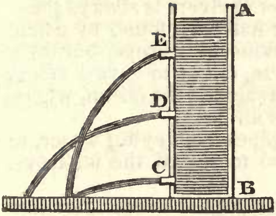

Fig. 93.

202. The distance to which water will spout from horizontal jets, at different depths below the surface, will be greatest in those which are midway between the top and bottom. Thus, a jet from D, figure 93, will strike the ground at a greater distance from the cistern A B, than one issuing either from C or E.

203. The quantity of water that will be discharged from an orifice in a given time depends considerably upon the nature of the orifice. Thus, if an aperture of a given size be made in a vessel of sheet-iron, it is found it will not discharge as much water as if the sides were thicker; or, which is still better, if a short tube were inserted just even with the inner surface of the vessel. The reason of the difference is no doubt to be attributed to the partially opposing cross-currents that are more liable to be found in the case of a vessel with thin sides and without a tube. Different modifications of the pipe, not here detailed, have peculiar effects in increasing or diminishing the flow of the water.

204. The above remarks apply only to pipes of very moderate length in proportion to their diameter; the effect of long pipes is always to retard the flow of water by reason of the friction against their sides. And this retardation by friction is proportionally greater in small pipes than in large ones, so that a pipe 2 inches in diameter will discharge in a given time 5 times as much water as one only 1 inch in diameter. Were it not for the greater friction, proportionally, of the small pipe, the larger would discharge only 4 times as much as the smaller; or, the quantities discharged would be proportional to the areas of their sections.

205. Water in rivers and canals is much retarded in its course by friction against the bottom and sides, so that the motion is much the most rapid at the surface and in the middle of the stream. The resistance is also very much increased by the great unevenness of the surface over which the water glides, and by obstacles, as stones and other heavy bodies lying at the

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Quest. 202. If several orifices are made in the side of a vessel filled with water, from which will the water jet farthest? 203. Does the quantity of water that escapes from an orifice depend upon its nature? How does a short tube affect the discharge? What reason is given? 204. To what pipes only does the explanation apply? Is there any friction between liquids and solids? How much more water will a pipe 2 inches in diameter discharge than a tube only 1 inch in diameter? 205. Is water retarded in rivers and

bottom; so that the velocity of water in rivers is always greatly less than it otherwise would be. It has been found by calculation that the water of the river Rhone in Europe, but for the resistance it meets with in its course, ought to have a velocity of about 170 miles per hour before reaching the ocean, whereas its real velocity is only 4 or 5 miles an hour.

Sudden turns in the course of pipes conveying water, and in the course of rivers, operate also to retard the water very much.

206. A solid in motion through a liquid meets with much resistance from it, proportional to its size and form. A piece of board, it is well known, requires much more force to move it through water when its flat side is presented in the direction of its motion, than when it is moved in the direction of its edge.

The oarsman in plying his boat always keeps the flat surface of the blade of his oar in the direction in which he pulls; but on removing his oar from the water he presents the edge in the direction in which it is to move.

The sailing of a ship depends much upon her form, on account of the resistance of the water; and great effort has been made to determine the form in which this resistance shall be the least possible. To attain this object, it is found that regard must be had to the shape, not only of the forward part or bow of the ship, which is presented in the direction of her motion, but also to that of her stern. This must be of such a form that the water may readily and freely close around her as she glides through it, else a great depression of the surface will be observed immediately behind her, below the common level, in consequence of which much of the propelling force, whether it be wind or steam power, will be lost. The resistance of the water to a vessel moving through it increases rapidly with the speed. If it requires a certain force to propel a ship 5 miles an hour, it requires much more than double the force to propel her at double this speed; and so of any other proportion.

The forms of the bodies of fishes and birds are found upon examination to be admirably adapted by nature to facilitate their movements through the fluids which constitute their proper elements.

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canals? Is the motion of the water most rapid at the top or bottom? What would be the velocity of the water in the river Rhone in Europe, on reaching the sea, if it was not retarded in its course? What is its actual velocity? 206. In what direction may a piece of board be moved through the water with the least resistance? Does the sailing of a ship depend upon her form? Must regard be paid to the form of her stern, as well as to the form of her bow? What must be the form of a ship's stern, in order that she may sail well? Does the resistance increase with the speed? Are fishes fitted for gliding easily through the water?

207. *Hydraulic Machines.*—Water has been used as a power for propelling machinery from a very early period. For this purpose it is used in two modes, either by causing it to act simply by its weight on the circumference of a wheel, or by the impulse of its motion when issuing from under strong pressure. The motion is then transmitted in the usual manner, by wheel-work or other contrivances, to the machinery which it is required to move. Sometimes these two modes are combined.

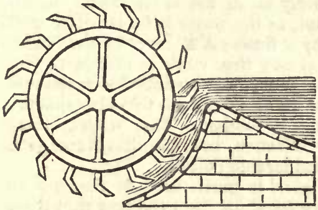

Fig. 94.

208. In the case of the *breast-wheel*, the water acts in the former of the two modes above described Figure 94 represents a section of this wheel perpendicular to the axis. This wheel is constructed with fixed boxes or buckets, which on one side are more or less erect in their position, and therefore capable of retaining the water, which acts by its weight, and turns the wheel, until, approaching the lowest point, they are, one after another, emptied, and ascend in an inverted position on the opposite side. It is of course advantageous to cause the water to fall upon the wheel as near the top as may be, in order to fill as many of the buckets as possible; but sometimes it is made to strike the wheel very low, even below a line horizontal with its axis. But, in this case, it is usually made to act also by its momentum acquired in issuing from the reservoir or dam above.

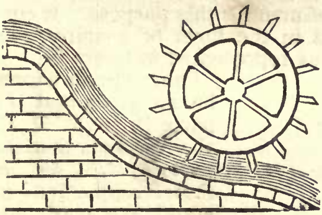

Fig. 95.

209. The *undershot-wheel*, which is represented in figure 95, is an ordinary wheel turning on an axis, and furnished with a number of flat boards placed at equal distances on its rim, so as to project from it in directions nearly diverging from its centre, and having their flat faces of course nearly at right angles to the direction of the stream. These are called float-boards. The wheel is then so placed that its lower edge is immersed in the stream, called the mill-course; and the current of water acting against the float-boards by its momentum causes it to revolve in the direction of the stream. The water may be allowed to issue over the top of the reservoir by a sluice-way, as shown in the figure, and strike the wheel by the momentum acquired in its fall; or the perpendicular wall of the reservoir may be placed near to the wheel, and the water allowed to escape by a gate-way at the bottom, nearly on a level with the bottom of the wheel. The velocity given it in this case by the pressure of the "head of water" above will be the same (§199) as will be acquired in the preceding case by its descent.

Quest. 207. Has water been long used for propelling machinery? In what two ways is it made to act? 208. How does it act in the case of the *breast-wheel?* How is it constructed? 209. How is the *undershot-wheel* turned? Why is this name applied to it?

This kind of wheel is sometimes called a tide, or stream-wheel, and is said to be the oldest construction in use.

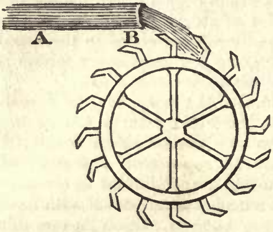

Fig. 96.

210. The kind of water-wheel represented in figure 96, is called an *overshot wheel.* Like the breast-wheel, on its rim a number of buckets are constructed to contain water, which acts by its weight, precisely as in the breast-wheel, to turn it; but, as the water is let on quite at the top by a flume, A B, more of the buckets will at any time while in motion be filled. If the water has considerable momentum when let on the wheel, this also assists in giving it motion. This wheel, though very effective, has the disadvantage of requiring for its use a waterfall of considerable height.

211. A water-wheel called the *tub-wheel* is much used in flouring and other mills in this country. It receives its name from the fact that it consists of a large tub without a bottom, in the inside of which, on the arms, the *float-boards* are placed, the wheel being in a horizontal position, and having the shaft perpendicular. The water is conveyed to the wheel by a proper flume or sluice-way, and acts solely by its impulse.

212. Most machines used for raising water at the present day, act in part at least by atmospheric pressure, and will therefore be considered in the Chapter on Pneumatics; but one or two will claim to be noticed here.

The *cochleon*, or *screw* of Archimedes, seems to have been one of the earliest inventions of man for this purpose. It consists of a tube wound around in the form of a spiral, and placed in an inclined position, as represented in figure 97.

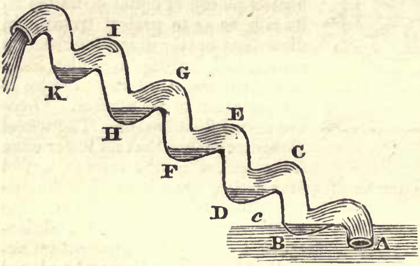

Fig. 97.

The inclination must be so great that the parts B, D, F, H, K, shall be lower than the parts A, C, E, &c. If, therefore, portions of liquid are contained at the former points, it will not escape, since these parts of the tube constitute dish-like cavities capable of retaining it. Let us suppose the tube fixed on an axis now to be turned as if to screw it down, while the lower end is immersed in water; a portion will enter at A and pass on to B as down an inclined plane. But as it turns, the

Quest. 210. How is the *overshot-wheel* constructed? How does the water act upon this wheel? What disadvantage has this wheel? 211. How is the *tub-wheel* constructed? 212. In what chapter are the different kinds of pumps described? What is the *cochleon* or *screw* of Archimedes? How is the

part B, keeping its same position with reference to the water contained in its cavity, will gradually rise to *c*, and so on to D, while another whirl of the spiral will take its place at B. Thus, a portion of water will be carried or up-screwed, up—we may say—quite to the top, to be there discharged. At the same time, other portions will be ascending in the several whirls of the spiral, each in turn delivering its portion of the fluid. As before intimated, it is necessary that the whole should be so much inclined that there shall be a descent from A to B, from C to D, &c., so as to form cavities for containing portions of water.

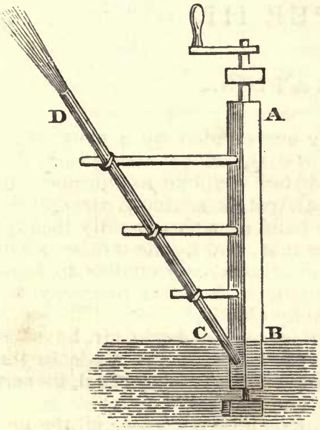

Fig. 98.

213. The *centrifugal pump* is an instrument for raising water by means of the centrifugal force which is given to a column of it. Let A B, figure 98,* be a solid piece of timber, and C D a tube attached to arms projecting from it; and let the whole stand in water supported upon a pivot on which it may turn. If it is now made to turn rapidly, such a centrifugal force will be given to the column of water in the tube C D, that it will be thrown from the mouth D in every direction with great violence.

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water raised by means of it? Why must it be placed in an inclined position? 213. What is the *centrifugal pump?* How is it worked?

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* Ewbank's Hydraulics, page 230.

CHAPTER III.

PNEUMATICS.

214. The earth is constantly surrounded by a great mass of gaseous matter, called the *atmosphere* or *atmospheric air*, which extends a considerable distance above its surface. Its presence, when it is perfectly at rest, is scarcely perceptible; but, if we attempt to move the hand or a fan rapidly through it, it manifests itself by its resistance, and by the motion which is communicated to it. It obeys laws very similar to those treated of in the preceding Chapter, but not precisely the same, as air is considered perfectly elastic.

The various other gases, besides atmospheric air, have the same mechanical properties; and the remarks made in this chapter concerning atmospheric air may, in general, be considered as applying equally to them.

215. Air is a material substance, and possesses all the properties of matter, as impenetrability (§ 9), weight, inertia, &c. It has also a very feeble blue colour, as is evident from its causing distant hills and mountains to appear of this colour. Other gases also possess colour, as chlorine, which is green.

The atmosphere which surrounds the earth, as well as solids and liquids upon its surface, is retained there by its gravity or weight. This will be made evident as we proceed.

216. It is the resistance, occasioned by the inertia of air, that causes all bodies which are put in motion in it gradually to come to a state of rest; at the same time, a portion of its own particles is put in motion by a solid or liquid projected in it.

Quest. 214. By what is the earth constantly surrounded? Why is not the pressure of the atmosphere perceptible? Does it obey the same laws as liquids? Are there other gases besides atmospheric air? Have all the same mechanical properties? 215. Is air material? Has it the properties of matter, as weight, impenetrability, inertia, &c.? Has it any colour? How is this shown? How is the air retained upon the earth? 216. Why do bodies put in motion in the air soon come to a state of rest? How is this shown by means of the apparatus represented in figure 99? Why do both mills move equally long in the exhausted receiver, though one stops much before the other when made to revolve in the open air? By what means do birds sus-

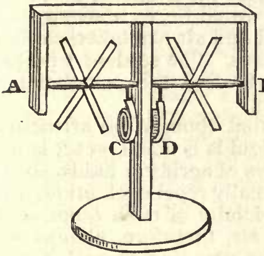

Fig. 99.

This property is well illustrated by the following apparatus. A and B, figure 99, are two separate movable axes, each having four fans or vanes composed of thin slips of brass inserted in it by one end. In one of them, A, they are inserted edgewise; that is, so that when the axis is turned, the edges are presented in the direction of the motion; but in B, they are inserted so that the faces are presented in the direction of the motion. C and D are two springs of equal strength which are made to act against pins in the axes A and B, and turn them, a slider not represented in the figure holding them in place until everything is in readiness. By means of the slider, both are set in motion at the same time, and with equal velocities; but as the resistance of the air to B is much greater than to A, in consequence of the different positions of the vanes, it comes to rest much sooner than the other. If, however, they are placed under the receiver of an air-pump, and the air exhausted, they will be found upon being again put in motion as before, to move with equal velocities, and to continue in motion the same length of time. It is this property which enables birds (§ 60) to raise themselves in it, by means of their wings, above the surface of the earth. The wings being spread and struck on the broad surface of the air beneath them, are resisted, by the inertia of the air, which forms a fulcrum or prop, on which the bird rises by the "leverage of its wings."

217. As the lower parts of the atmosphere must constantly sustain the weight of the upper portion, they are pressed together with great force, and their density much increased. As we ascend above the surface, the density of the air rapidly diminishes, and at the height of about 3 miles is reduced to one-half; at the height of 6 miles, to one-quarter; and at the height of 9 miles, to only one-eighth of its density at the level of the sea. It extends to the height of about 40 or 45 miles; but if it had a uniform density equal to its present density at the surface, its height would be only about 5 miles. The whole mass of the atmosphere surrounding the earth is computed to be equal to that of a sphere of lead a little more than 60 miles in diameter; upon the supposition that the earth is a perfect

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tain themselves in the air? What serves as the prop for their wings? 217. Why are the lower parts of the air more dense than the more elevated portions? What is the density of the air at the height of 3 miles? What at the height of 9 miles? How high does the atmosphere extend? If the whole atmosphere was reduced to a uniform density equal to that at the surface,

sphere, 8000 miles in diameter, and that the height of the atmosphere, if it was of uniform density, would be, as above stated, 5 miles. The specific gravity of lead and air are taken as they are set down in recent approved tables. The student who has some knowledge of mathematics will find the calculation a pleasing and not a tedious operation.

218. We have seen above (§ 14) that though the attraction of cohesion among the particles of liquids is small, yet it is not altogether wanting; but the particles of aeriform fluids, so far from showing any attraction for, actually repel each other, and are kept together or in the close vicinity of each other, only by external pressure. A mass of air, therefore, always expands as soon as any portion of the pressure to which it is subjected is removed.

219. Wind is nothing more than the air in more or less rapid motion, and, like other bodies, its force depends upon the quantity put in motion and its speed. (§ 95). The effects of this force are seen in the motion of ships which are propelled by it through the sea, in the motion of the windmill, and in the terrible devastations of the hurricane, as it sweeps before it trees, and buildings, and everything movable with which it comes in contact.

The weight of the air present in any given space, as an apartment in a building, is much greater than most persons generally suppose. Suppose a gentleman's parlour to be 20 feet square and 12 feet high, taking the weight of 100 cubic inches of air at 31 grains, (the true weight is 31.01 grains,) the weight of the whole air in the room will be found on calculation to be more than 367 pounds avoirdupoise. Let the student make the estimate.

AIR-PUMP.

220. The air-pump is indispensable in demonstrating the various properties of the air and other gases; and we therefore give a description of it before proceeding further.

This instrument, in its most simple form, consists of a barrel, A B, figure 100, usually made of brass, and carefully turned out inside, so as to admit of the piston, P, which is very accurately fitted to it, to move freely up and down in it by means of the handle, H. At the bottom, *a*, is a small valve opening upward, made very light, which, when shut, perfectly closes the small aperture beneath it. It is represented in the figure as open. In the piston, P, is another similar valve, *b*, which also opens

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what would be its height? What would be the diameter of a solid globe of lead to contain the same amount of matter as is contained in the atmosphere? 218. Is there any cohesion among the particles of air? What only keeps the particles in the vicinity of each other? What is always the effect of removing the pressure upon a volume of air? 219. What is wind? In what do we see its effects? What is the quantity of air ordinarily present in a room 20 feet square and 12 feet high? 220. How is the air-pump constructed in figure 100? How is its action explained by figure 100?

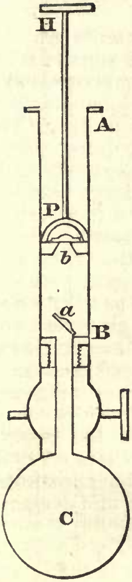

Fig. 100.

upward. Now, when the piston is pressed downward, the valve in it is opened by the air in the barrel beneath it, which is prevented from escaping by the valve, *a*; but it closes by its own weight as soon as the piston reaches the bottom. When the piston is raised, the valve, *b*, in it being closed, all the air in the barrel above it is lifted out, and a vacuum would be produced below it but for the air rushing in through the valve, *a*, at the bottom.

221. Suppose the barrel to be now screwed on to a globular vessel, C, fitted with a stop-cock, which we will suppose open. As the piston, P, is raised, the air from without not being permitted to enter the space in the barrel below, it can be filled only by the expansion of the air in the vessel, C, which, in consequence of its elasticity, (a property to be illustrated more fully hereafter), will immediately take place. When the piston again descends, the lower valve, *a*, closes, and the air in the barrel is condensed, until it becomes equal in density to the surrounding atmosphere; the further descent of the piston will then cause the upper valve, *b*, contained in it, to open and allow the air below it to escape. As the piston again ascends, a further expansion of the air in the vessel, C, takes place to fill the barrel by the opening of the lower valve; and thus, by the working of the piston, successive portions of the air in C are removed, until at length its elasticity becomes so feeble, by reason of the small quantity which remains within, that it is incapable of lifting the valve *a*, when of course the further exhaustion must cease. It will be seen, therefore, that the air-pump is incapable of producing a perfect vacuum. By turning the stop-cock, the vessel, with the small quantity of air it contains, may be separated from the pump by unscrewing it at B.

To the simple air-pump of this construction, the name *syringe*, or *exhausting syringe*, is often applied. There are various modifications of it, which it is not necessary here to describe.

222. Such a pump would be effectual, but of course slow, in its operation. In order to make the instrument exhaust more rapidly, and to adapt it better for use, it is generally made with

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Quest. 221. Does the air-pump remove all the air from a vessel? Why can it not produce a perfect vacuum? Does the quantity removed by each elevation of the piston constantly diminish? 222. Why is the common air-pump made with two barrels? How do these barrels connect with the plate

two barrels, and provided with other conveniences, as described below.

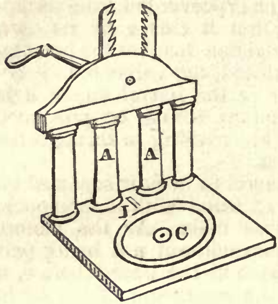

Fig. 101.

Figure 101 represents an air-pump of the ordinary construction. A A are the two barrels provided with valves and pistons precisely like that represented in figure 100. At the bottom they connect with a small tube, I, which extends in to the centre of the large circular plate, C, so that when the pump is worked, the air is drawn in at the aperture in the centre. The surface of this plate is ground perfectly plain and smooth, so as to make an air-tight joint with a glass receiver, R, figure 102, which has its lower edge ground and polished in a similar manner. I and C are supposed to correspond to the same letters in figure 101. By the side of the barrels, A A, figure 101, are two pillars screwed firmly into the board which constitutes the base of the instrument, and designed to support a concealed toothed wheel that, by means of the handle, works the piston-rods, seen at the top of the figure. In front of the barrels is a small stop-cock, not shown in the figure, which opens into the tube, I, to let in the air when necessary, after an exhaustion has been produced. When any substance is to be submitted to experiment, it is put on the plate, C, the receiver placed over it and the air exhausted.

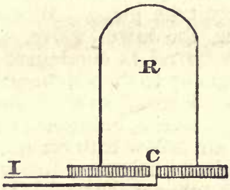

Fig. 102.

To enable the operator to exhaust the air from vessels of other forms, besides that of the receiver, R, described above, a thread is usually cut in the hole, C, in the centre of the plate, into which a tube may be screwed.

The air-pump has from time to time been constructed in a great variety of forms besides the above, which, however, fully illustrates the principle on which it acts.

223. The *condensing syringe* is the converse of the exhausting syringe, or air-pump just described, and is designed to condense the air or increase its density.

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of the pump on which the receiver is placed? What is the usual form of the receiver used with an air-pump? How are the pistons worked? Where is the substance placed that is to be submitted to experiment? How may other vessels be connected with the pump so as to have the air exhausted from them? 223. What is the design of the *condensing syringe?* How is it constructed? In what direction must the valve open?

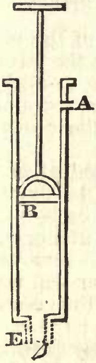

Fig. 103.

This consists of a brass barrel, furnished with a valve, E, figure 103, opening downwards, and having a perforation in the side at A. The piston, B, is solid, and when it is pressed down it forces the air in the barrel through the valve, E. On raising it, the air is prevented from following it by the closing of the valve E, and a vacuum is formed until it reaches the aperture, A, when a fresh portion of air enters, to be in turn forced through the valve E. By means of the screw at the bottom, this, like the exhausting syringe, may be attached to a vessel as the globe C, figure 100; and, by working it, successive portions of air could be driven in as long as the strength of the vessel is sufficient to retain it.

By means of these two pieces of apparatus, all the important experiments illustrating the general properties of gaseous bodies may be performed.

PRESSURE AND ELASTICITY OF THE AIR.

224. As the air is confined to the earth by its gravity or weight (§ 215) it must of course press upon the earth's surface precisely as any other substance would. This pressure, though the ancient philosophers were entirely ignorant of its existence, may be shown, and its amount accurately ascertained by several very simple experiments.

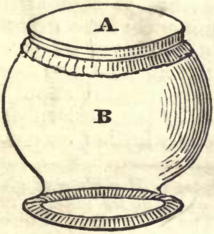

Fig. 104.

225. If a glass of the form of B, figure 104, having a piece of bladder, A, tied over it when wet, and then allowed to dry, is placed upon the plate of the air-pump, and the air gradually exhausted, the piece of bladder will at first be seen to curve downward by the pressure above, and at length it will give way with a loud report.

If, instead of the piece of bladder, A, the palm of the hand be placed on the glass, upon the exhaustion of the air from beneath, it will be held down with such a force as to make it difficult to remove it without first readmitting the air.

Quest. 224. Does the air press upon the surface of the earth just as other bodies? Were the ancient philosophers acquainted with this property of the air? 225. How is the pressure of the air shown by a piece of bladder tied

If a piece of thin plate glass were used, it would be incapable of resisting the pressure, and would be broken.

226. In these experiments, before the exhaustion of the air from the glass receiver, the downward pressure upon the piece of bladder or upon the hand, is of course the same as afterwards; but it is counterbalanced by the upward pressure of the air within; when this is removed, the effects of the downward pressure are seen as above shown.

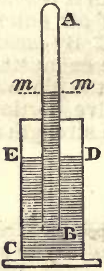

Fig. 105.

If a glass tube, A B, figure 105, closed at one end, be partly filled with water, and the finger held upon the open end to prevent the escape of the water until it can be inverted and immersed in a vessel, C, of the same liquid, upon the removal of the finger it will be found the water will not fall to the surface of the liquid, D E, in the vessel, but will remain suspended in the tube, as at *m*.

227. If the tube, instead of being partly filled in this manner, had been open at both ends, and connected with an air-pump, as the air was exhausted the water would gradually rise in it until it was quite filled, provided its perpendicular height should not be greater than about 33 feet. If the air were again admitted, the water would instantly fall to its former level.

Now, the standing of the water in the tube in the first of these experiments above the level of that in the vessel, and its gradual rise in the tube in the second experiment, are occasioned by the pressure of the atmosphere on the surface of the water without the tube. In the last experiment, before the exhaustion is commenced, the air presses on the surface of the water equally both within and without the tube; but as soon as the exhaustion of the air in the tube is commenced, the greater pressure on the surface of the water outside forces a portion to enter the tube to supply the place of the air that has been removed. When the water has risen to the height of about 33 or 34 feet, the column is just balanced by the atmospheric pressure, and no exhaustion will produce any further ascent.

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over the mouth of a receiver prepared for the purpose? If a plate of glass were used instead of the piece of bladder, what would be the effect? 226. What if the palm of the hand were used? Why is not this downward pressure ordinarily perceptible? If a glass tube closed at one end is partly filled with water, and the finger held upon the open end until it can be inverted and held in a vessel of water, why does not the water fall upon the removal of the finger? 227. If the tube was open at both ends, and connected by another tube with the air-pump, what would be the effect of exhausting the air? What is the cause of the standing of the water in the tube above its level in the basin, and its rise in the tube when the air is exhausted? How high will the water rise in an exhausted tube?

228. If a liquid lighter than water is used, it will rise higher than water, in proportion as its specific gravity is less.

So also the height to which liquids heavier than water can be made to rise, will be less than 34 feet, in proportion as their specific gravity is greater than that of water.

229. This is well illustrated in the case of mercury, which is about $13\frac{1}{2}$ times as dense as water. Thus, 34 feet, or 408 inches, divided by $13\frac{1}{2}$, gives $30\frac{2}{9}$ feet, which is about the height to which mercury will usually be found to rise.

230. As the column of mercury which will be sustained by the atmosphere is only about 30 inches in height, it will be easy to make the experiment to test our conclusions.

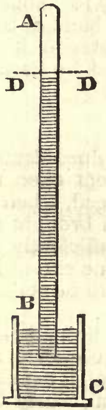

Fig. 106.

Having procured a tube of glass, as A B, figure 106, not less than 33 inches in length, and closed at one end, fill it quite full of pure and clean mercury, and then pressing firmly against the open end with the finger to prevent the escape of the mercury, invert it in a vessel of mercury, C, and remove the finger. Supposing the tube to be 33 inches in length, and one inch at the bottom immersed beneath the mercury in the vessel, the height of the column will at first be 32 inches; but, on the removal of the finger, it will be seen instantly to fall to D D, and stand there at about 30 inches, the space in the tube above this being entirely empty.

This vacant space above the surface of the mercury is called the *Torricellian vacuum*, from the name of the individual who first performed the experiment. It is usually considered the most perfect vacuum that can be formed by man, at least when the proper precautions are taken in forming it.

That it is really the pressure of the atmosphere which sustains the mercury in the tube in this case, is made plain by placing the vessel of mercury with the tube, under a tall receiver on the plate of the air-pump, and exhausting the air; the mercury will be seen to fall as the exhaustion proceeds; and, if a perfect vacuum could be produced, it would fall in the tube quite to a level with that in the vessel.

Quest. 228. If a liquid lighter than water is used, what will be the result? If heavier, will it rise as high? 229. How high will mercury rise in an exhausted tube? Why does it not rise as high as water? How much heavier is mercury than water? 230. How may the experiment be made with mercury? Supposing the tube to be 33 inches in length, what will be contained above the mercury? What is the *Torricellian vacuum?* Is it the most perfect vacuum that can be produced? What will be the effect if the tube and mercury are placed under a receiver, and the air exhausted? Is it certain that it is the atmospheric pressure that sustains the mercury in the tube?

231. *The Barometer.*—An instrument prepared as just described constitutes the ordinary barometer, which is designed to show the pressure of the atmosphere, and any changes that may take place in it. The tube is generally made about 32 or 33 inches long; and at the upper surface of the mercury a scale is placed, very accurately divided into inches and tenths of an inch, and provided with a vernier, so that variations of a hundredth of an inch may be measured. Instead of an open vessel, C, in which the mercury is here contained, a wooden cup is generally used, having the tube cemented into the top, and the bottom made of leather, so as to yield readily to the atmospheric pressure. The object of this is to prevent accident by the spilling of the mercury, which would be likely to happen if the cistern containing it was open. On the other hand, if the cistern were made tight, and of an inelastic substance, it is plain that the mercury within would not be affected by variations of atmospheric pressure.

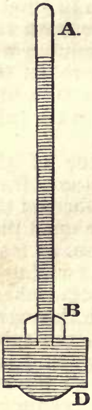

Fig. 107.

In figure 107, A B, is the tube which is glued firmly into the wooden cistern, C, which is kept open at the bottom until the mercury is introduced, when a piece of leather, D, is glued on. When brought to its proper position, this leather yields sufficiently to allow the mercury to fall and rise to some extent in the tube, and the mercury is not liable to be spilled as just stated.

By means of this instrument it has been determined that the pressure of the atmosphere, even at the same place, is not uniform; for, though it usually sustains the mercury at the height of nearly 30 inches, at the level of the sea, yet it will sometimes fall as low as 28 inches, or rise as high as 31 inches. In some cases these changes are very sudden, but usually they take place gradually.

232. No less than twelve or fifteen modifications of this instrument, besides the above, have been proposed by different individuals; but one only will be described here. This is the *wheel barometer*, invented by

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Quest. 231. What is the design of the barometer? How does it show changes in the atmospheric pressure? How is the barometer made so as to be influenced by atmospheric pressure, and at the same time prevent the escape of the mercury? Why might not the cistern be made perfectly air-tight of an inelastic substance? Is the pressure of the air always uniform at the same place? What is the usual height of the mercury at the level of the sea? How much may it vary above and below 30 inches? 232. How may different modifications of this instrument have been produced? Is it believed

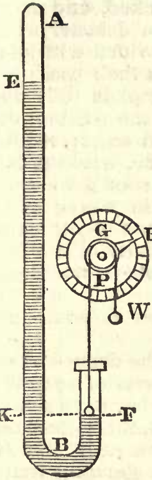

Fig. 108.

Hooke. It is frequently used as an ornament for parlours, "to give them an air of Philosophy;" but its indications are not very accurate. It is made just as the barometer described above, except that instead of the cistern at the bottom, the tube is bent upward, as seen in figure 108. The atmospheric pressure acts upon the surface, F, of the mercury, and sustains the column, E K, which is above the level, F K. The columns, F B and B K, support each other. If the pressure is at any time increased, the surface, F, will be depressed, and the surface, E, will rise towards A, by an equal amount; consequently, the difference of level between F and E, or the mercurial column which is supported by atmospheric pressure, will be increased by twice the space through which F is depressed. When the pressure of the atmosphere is diminished, the surface, F, will rise, and E will fall. On the surface F, a weight is placed, to which a cord is attached, passing over a wheel, P, with an index or pointer, H, and having another weight, W, at the other end. Now, as the surface F rises or falls, a similar motion of the weight on its surface is produced, and the pointer is made to turn on its axis; and, by having a circular plate, G, properly graduated and attached to the instrument just behind the pointer, the variations of the height of the mercurial column are beautifully indicated. Usually, around this graduated circle, the words "Fair," "Stormy," &c., are engraved, as if these states of the weather might be expected always whenever the mercury stands at the height indicated by them; which, however, is by no means the fact.*

But long observation has fully proved that there is a connection between *changes* in the height of the barometric column, and changes in the weather. Thus, it is said that, in general, the rising of the mercury indicates fair weather, and its falling the reverse. When a very sudden and great fall occurs, especially at sea, a storm, with high wind, is to be expected. But none of these indications are to be considered by any means certain. Instances are however given, in which captains of vessels, by heeding the indications of the barometer, and making seasonable preparations for the approaching storm, have saved themselves from its effects, which otherwise would very probably have been disastrous. The dreadful storm that occurred on lake Erie the last autumn (1844), we are informed by Mr. Haskins, a scientific gentleman of Buffalo, was plainly indicated at that place several hours before its commencement there, by a sudden and unusual fall of the mercury in the barometer. About the time the mercury was thus falling, several

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there can be traced some connection between changes in the weather and changes in the barometer? What does the rising of the barometer indicate? What is indicated by a fall? What is said of the storm of 1844 upon lake

steamboats left the harbour, and were wrecked, and many lives lost in their encounter with the gale; a disaster which might have been avoided had they been provided with good barometers, and their officers acquainted with their use.

It would, without question, be difficult to explain fully why this relation between changes in the state of the weather and changes in the height of the barometer should exist; but it is very easy to conceive that a storm in any place, which is only a violent commotion in the atmosphere there, should have the effect to increase or diminish the pressure in places in the vicinity. And, as storms move over the surface of the earth, the place which at one hour is only in the vicinity of a storm, may shortly afterwards be the theatre of its most violent effects.

When used for this purpose, the barometer is sometimes called a *weather-glass.*

233. The *syphon-gauge*, used to determine the degree of exhaustion produced by an air-pump, is a barometer of a peculiar construction. It is evident that if the common barometer could be placed under the receiver of the air-pump, the exhaustion produced at any time would be correctly indicated by it, a fall of one-half, one-third, or one-fourth its length showing that a corresponding proportion of the air had been removed; but its length is so great, 30 or 31 inches, as to preclude its use.

Fig. 109.

The syphon-gauge, figure 109, is composed of a glass tube, A B C D, cemented firmly into a brass socket with a faucet at D, the part, B A, being filled with clean mercury. The mercury is kept in its place by the atmosphere, and therefore, when D is screwed in the pump so as to bring it in communication with the tube, I, of the air-pump, fig. 101, leading to the receiver, whenever the exhaustion is carried beyond a certain point it will fall. Let us suppose that the part, A B, is $7\frac{1}{2}$ inches in length, which is one-fourth of 30, whenever three-fourths of the air has been exhausted, the column of mercury, being no longer supported, would begin to fall, the lower surface at B rising at the same time. If a perfect vacuum could be produced, both surfaces of the mercury would stand at the line *m m.*

It has been said above that the height to which a column of water may be raised by atmospheric pressure is about 34 feet, or the column of mercury about 30 inches, though subject to considerable variation. But these heights apply only to places

Erie? 233. What is the design of the *syphon-gauge* in the air-pump? How is it constructed? When this gauge is $7\frac{1}{2}$ inches in height, how far must the exhaustion be carried before it is affected? Can a column of water be raised 34 feet above the surface on a high mountain? What is the reason? Will

situated near the ordinary level of the sea. As we ascend above this, and of course above a portion of the body of the atmosphere, the mercury in the barometer is observed to fall. If the atmosphere was of uniform density at all distances above the surface, this fall of the mercury would necessarily be uniform; that is, if an ascent of 100 feet above the level of the sea produced a fall of $\frac{1}{10}$th of an inch, then on ascending 200 feet it would fall $\frac{2}{10}$ths of an inch, and so on for any other height. But this is by no means the case; it is found by experiment that the mercury falls much more rapidly while ascending the first hundred feet, than it does in passing through the second; and more the second hundred feet than in the third, and so on. This is in consequence of the density of the air diminishing as we ascend from the surface by reason of the diminished pressure. (§ 217). The stratum of air at the surface is pressed by the whole weight of the superincumbent atmosphere; but, as we ascend above this, the quantity of the superincumbent fluid being less, the pressure will be less, and also the density.

234. It is found that at 3 miles above the level of the sea the mercury stands at about 15 inches, the height of the column being diminished about one-half in this distance; and it has been calculated, that at the height of 9 miles, it would stand at $3\frac{3}{4}$ inches; and at 15 miles, only 1 inch. (§ 217).

235. It will be seen from the above, that this instrument may be used for the measurement of heights; this is indeed one of the most important purposes it serves. But to ensure accuracy in the results, several very important precautions are to be taken. One of the chief causes which affect its results is variation of temperature between the stations at the base and top of the mountain, the height of which is to be measured; but rules have been devised for making the necessary corrections for this and other sources of error; and the heights of mountains, especially at a distance from the sea, can probably be determined as accurately by this instrument as by any other means, and with much less expense and trouble.

236. The weight of the whole atmosphere is equal to that of a sea of mercury about 29 or 30 inches in depth, or to a sea of water about 33 or 34 feet deep. Now, a column of mercury an inch square and 30 inches high, weighs very nearly 15 pounds avoirdupois; and this, therefore, must be the pressure of the atmosphere upon every square inch of the earth's surface. And as it is the nature of a fluid at any point to press equally in

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the mercury in the barometer descend equally for every ascent of 100 feet? 234. What is the height of the mercury in the barometer 3 miles above the surface of the earth? What would be its height 15 miles above the surface? 235. May the barometer be used for measuring the height of mountains? What precautions must be taken to insure accuracy? 236. What would be the depth of a sea of mercury, or of water, that would have a pressure upon the surface of the earth equal to that of the present atmosphere? What is the pressure of the atmosphere upon each square inch? How great pressure

every direction (§ 152), the lateral and upward pressures at any point will be the same; hence, though constantly subjected to this enormous pressure, we feel no inconvenience from it, nor are our motions impeded by it. The body of a man, the surface of which is about 2000 inches, must constantly sustain a pressure of about 30,000 pounds, or nearly 14 tons. It is easy to see, therefore, that if the downward pressure was not counterbalanced by an equal pressure in the opposite direction, we should be crushed to the earth by a force altogether irresistible.

237. *Other instances of the effects of Atmospheric Pressure.*— Various operations in nature and art, which we daily witness, are dependent upon the pressure of the atmosphere. The Magdeburgh hemispheres afford an instance.

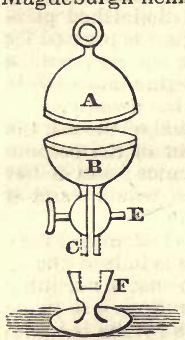

Fig. 110.

Two hollow brass hemispheres, A and B, figure 110, are accurately ground so as to fit each other at the edges, and form an air-tight hollow sphere. One of them has a tube with a faucet, E, and screw, C, by which it may be connected with the air-pump, and to which a ring for a handle, like that on the hemisphere, A, may be screwed after it has been exhausted and separated from the pump. To exhaust the air, the two hemispheres are to be placed together with a little tallow in the joint, if necessary, to make them perfectly tight, and it is then to be screwed into the hole in the centre of the plate in the air-pump. When exhausted, they will be held together by a strong force, so that two persons taking hold by the rings or handles will hardly be able to separate them. The part, F, is merely a stand for holding the hemispheres when not in use.

238. If a circular piece of tolerably thick leather, 2 or 3 inches in diameter, be moistened, and then placed closely upon a smooth surface, it will adhere with considerable force; if it be placed upon a smooth stone, and a string attached to the centre, the stone, though weighing several pounds, may be lifted by it. This is owing to the exclusion of the air from between the stone and the leather, the drawing of the leather at its centre from the stone tending to produce a vacuum. The force with which the two surfaces will be held together will be equal to about 15 pounds for every square inch of the surfaces in contact.

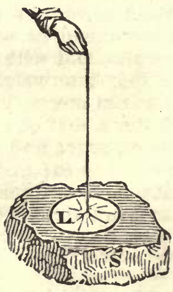

Fig. 111.

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does the body of a man constantly sustain ? Why is he not pressed by it to the earth ? 237. How are the Magdeburgh hemispheres constructed ? How are they used ? 238. How may a circular piece of leather be made to adhere to a smooth stone by atmospheric pressure so as to lift it ?

The experiment is represented in figure 111; S, the stone, and L, the piece of leather.

239. The ability of some insects, as the house-fly, to walk on ceilings and other smooth surfaces presented downward, and even on smooth panes of glass, is said to be owing to the peculiar formation of their feet, by which they are made to adhere to the surface in the manner of the piece of leather in the above experiment. The feet of the common tree-toad of New England (*Hyla versicolor*), it is believed, also act in part on the same principle.

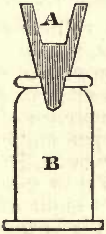

Fig. 112.

240. Let B, figure 112, be a receiver, in the top of which a piece of wood is accurately fitted with an excavation, A, in it, into which some mercury may be poured. On exhausting the air from B, by placing it upon the plate of the air-pump, the mercury will be forced through the pores of the wood by the external pressure, producing a beautiful shower of the metal.

241. The upward pressure of the air may be shown very beautifully in the following manner. Take a glass tumbler, or other taller vessel if desired, and fill it with water quite full, and carefully place a piece of paper over the surface, pressing slightly upon it with the hand. Then suddenly invert the vessel and remove the hand; the water will be retained in it, its whole weight being sustained by atmospheric pressure. Usually, the surface will curve upward a little, as shown in figure 113. The paper serves to prevent the water from breaking and falling in drops or fragments.

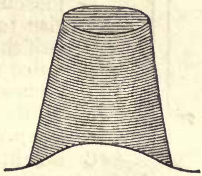
Fig. 113.

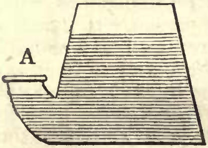

Fig. 114.

242. Ink-bottles are sometimes constructed on this principle, of the form represented in figure 114. The design is to prevent the drying of the ink, which is occasioned by too large a surface being presented to the atmosphere. The only opening the bottle has is at A; by turning this upward the ink may be poured in, and when the bottle is nearly filled, and turned back to its upright position, it is prevented from escaping by the atmospheric pressure. The pen is introduced at A, which must be of sufficient depth for this purpose; and when the quantity of fluid in this part is sufficiently reduced, a bubble of air enters, and a portion of the ink in the body of the vessel is permitted to descend. The only disadvantage which attends the use of this ink-bottle is occasioned by the expansion of

Quest. 239. How do insects adhere by their feet to perfectly smooth surfaces? 240. How may mercury be forced through the pores of wood? 241. How may the upward pressure of the air be shown by means of a tumbler filled with water? 242. How is the ink kept in the ink-bottle repre-

the air above the ink by a rise of temperature, which will sometimes cause the fluid to flow out at the mouth, A.

243. *Elasticity and Compressibility of the Air.* — We have seen (217) that in consequence of the pressure of the upper parts of the atmosphere, the air near the surface is much more dense than at more elevated positions. There is no limit known to the amount of compression by pressure which atmospheric air admits of, though some of the gaseous fluids, as carbonic acid gas, chlorine, &c., are condensed so as to take the liquid form, when the pressure reaches a certain limit depending upon the temperature.

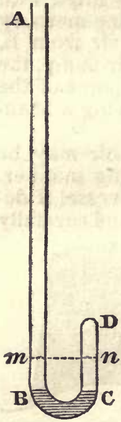

Fig. 115.

It is found by experiment that the volume or bulk of air, under different pressures, is less as the pressure is greater. This may be shown as follows. Let A B C D, figure 115, be a glass tube, closed at D, and bent in the form represented; and let mercury be poured in at the open end by inclining the tube a little until it fills the bend, B C, and divides the tube into two parts. If now more mercury is poured into the tube, its weight will press against the air at C, and cause the surface to rise towards D. We will suppose sufficient mercury is poured in to cause the surface, C, to rise to *n*, compressing the air in C D into one-half the space it at first occupied, which will require the column in the part A B to be about 30 inches in height above the line *m n*. The volume of air in C D is therefore diminished one-half, by the pressure of a column of mercury 30 inches in height, which we have heretofore learned is just equivalent to the ordinary pressure of the atmosphere. But before the mercury was poured in, the air in C D was under the pressure of 1 atmosphere, and, by adding as much more, or increasing the pressure to 2 atmospheres, the volume, as already stated, is reduced to one-half. If the pressure were increased so as to be equal to 3 atmospheres, the volume would be reduced to one-third; if increased to 4 atmospheres, it would be reduced to one-fourth; and so on for any other pressure. This could easily be shown, if the part of the tube A B was of sufficient length, by continuing to pour in mercury, and observing the height of the column and the space occupied by the air in D. When the column of mercury was 60 inches in height, only one-third of the space, C D,

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sented in figure 114? To what inconvenience is it subject? 243. Is there any limit to the compressibility of the air? How are some of the gases affected by strong compression? In what ratio does the volume diminish as the pressure is increased? How is this illustrated by means of the apparatus represented in figure 115? How much is the volume diminished when

would be filled with air; and when the column of mercury attained the height of 90 inches, the air in C D would be compressed into one-fourth the space it at first occupied, &c.

We have, then, this law, usually called the law of Mariotte, that *the volume of a gas will always be in the inverse ratio of the pressure to which it is subjected.*

244. As a necessary consequence of the above principle, it must follow, that the elastic force or expansive power of a portion of air will increase in proportion as the space it occupies is diminished; and the elastic force is diminished in proportion as the space through which it is allowed to expand is increased.

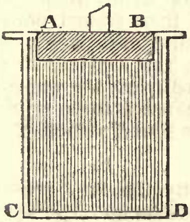

Fig. 116.

This may be better understood by the following illustration. Let A B C D, figure 116, be a cylinder in which the solid piston, A B, moves air-tight, and without resistance from friction; and let the distance from this piston to the bottom of the cylinder be just 12 inches. Let us suppose the weight of the piston to be just 20 ounces; then the elasticity of the air within is just sufficient to sustain this weight. Now, suppose a weight of 20 ounces is placed upon the piston, which will make the whole weight 40 ounces. The elasticity of the contained air not now being sufficient to sustain the piston, it will fall a certain distance, until the air is so much compressed, and its elasticity increased, that it is again supported in the position seen in figure 117. By measuring A C now, the distance will be found to be just 6 inches, the doubling of the pressure having reduced to one-half the volume of the contained air, and at the same time doubled its elasticity, as appears from the fact that it now sustains twice the weight it did before.

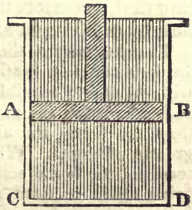

Fig. 117.

If, now, a weight of 20 ounces more were added to the piston, the air within would be further compressed, the piston descending to within 4 inches of the bottom. The compressing force would then be three times as much as at first; the contained air would be reduced to one-third of its original bulk; and its elasticity would be three times as great as at the commencement of the experiment.

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the pressure is doubled, trebled, or quadrupled? What is the law of Mariotte? 244. How is the elasticity of a portion of air affected by compression? How is its elasticity affected when it is allowed to expand? How is this illustrated by reference to figure 116? How much is the air in the cylinder compressed by doubling the weight of the piston? Can any force press the piston quite to the bottom of the cylinder?

A further addition of 20 ounces weight to the piston would cause it to descend another inch, thus reducing the air to one-fourth of its original volume, and increasing fourfold its elasticity. If still more weights were added to the piston, the same proportion would be observed between the pressures, the corresponding volumes of the air, and its elasticity; but no force could compel the piston to descend quite to the bottom of the cylinder.

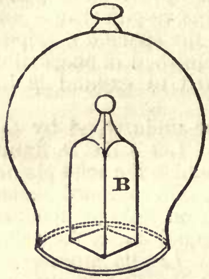

Fig. 118.

245. The ordinary elasticity of the air is of course just sufficient to resist the ordinary pressure of about 15 pounds to the square inch; but this force will sometimes produce unexpected effects. If a square bottle, B, figure 118, be firmly sealed, so as to be air-tight, and then placed under the receiver of the air-pump, when the air is exhausted from the receiver so as to remove the pressure from the outside of the bottle, the expansive force of the air within will often be found sufficient to burst it outward.

246. Let a bottle, B, figure 119, be partly filled with mercury, and a tube open at both ends be inserted air-tight through the cork; when it is placed under a tall receiver, A, and the air exhausted, the elasticity of the small portion of air in the bottle above the mercury will cause the mercury to be raised to a height corresponding to the degree of exhaustion produced. If all the air could be exhausted, the mercury would rise in the tube to the height of 30 inches.

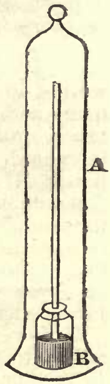

Fig. 119.

The elasticity of the air may also be shown by suspending an India-rubber bottle or bladder, containing a little air, with its mouth carefully tied, in the receiver of the air-pump, and exhausting the air. As the external pressure is removed from the bottle, the air within it expands, causing it to be greatly enlarged. When the air is again admitted into the receiver, the bottle contracts, the volume of the air within it being again reduced as at first. If the bladder, instead of being suspended so as to hang freely in the receiver, is placed in a cavity and loaded with weights, they will be lifted by the expansion of the air in the bladder when the receiver is exhausted.

247. The lungs of animals are alternately inflated and contracted, in the process of respiration, in a manner somewhat similar to the above. This important organ of animals is com-

Quest. 245. If a square bottle is corked and sealed perfectly tight in the open air, what will be the effect of placing it under the receiver of the air-pump and exhausting the air? 246. How may the elasticity of a portion of confined air be made to elevate a column of mercury in a tube? 247. How are the lungs of animals alternately inflated and then contracted? What do the

posed of soft elastic fleshy substance, situated in the chest, and filled with air-cells, which communicate with the external air by means of the wind-pipe and nostrils. By means of the diaphragm and ribs, the cavity of the chest is made alternately to expand and contract, by which corresponding motions of the lungs are produced.

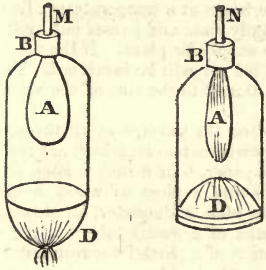

Fig. 120.

Figure 120 will serve to illustrate the process. Let M be a glass receiver, having a bladder, A, partly filled with air, suspended in it, communicating with the external air by means of a small tube passing air-tight through a cork at B; and having the bottom closed, also air-tight, by a leather bag, D. Now, by drawing out this part, D, by the hand, in consequence of the increased capacity of the receiver, the air is drawn in through the tube, B, into the bladder, and inflates it; but, by pressing upward on the part D, as shown in the figure, N, the air in the bladder is again forced out through the same tube, B, into the open air. By moving the bag, D, backward and forward in this manner, it is evident the air in the bladder, A, will be kept constantly moving in and out through the tube, B, precisely as in the process of respiration. In respiration, the diaphragm and muscles of the ribs serve the purpose of the leather bag, D, causing an alternate inspiration and expiration of the air through the windpipe and nostrils.

248. This constant inspiration and expiration of air from the lungs of warm-blooded animals is absolutely necessary for their existence. The air in the lungs is constantly undergoing a change which unfits it for the support of life, and it therefore requires to be renewed by fresh portions; an object which we see is admirably accomplished in the process of respiration just described. But, if a person or animal is confined in a small close room, by continually breathing the same air, the same change as takes place in the lungs will after a time be produced in the whole air of the apartment. Hence arises the necessity of having the air in our apartments constantly changed; or, in other words, to have them well ventilated. In ordinary dwelling-houses, in which the apartments are large in proportion to the number of occupants, and opportunity is frequently given for the passage of the air in and out by the opening of doors, there is no need of any special provision being made for their ventilation; but, when large assemblies are to remain for some time in comparatively small rooms, or

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lungs of animals consist of? How do they communicate with the external air? How is the cavity of the chest alternately expanded and contracted? What is illustrated by figure 120? 248. Is this constant inspiration and expiration of air necessary to animals? Why is it necessary that the air of our apartments should be constantly changed? Why is it not necessary to provide special means for ventilating ordinary dwellings? When large assem-

when from any cause there is not a free communication between the air of an apartment and the external atmosphere, injurious consequences will be certain to result unless some means are contrived to produce a circulation of the air. Various means have been suggested for this purpose, but usually it will be sufficient if a tube is provided leading from the upper part of the room through which the deleterious air of the room may escape, and another leading from the lower part to admit the fresh air from without. The impure air, as it comes from the lungs at a temperature a little above that of the surrounding air, immediately rises and passes out by the escape-tube, while a fresh portion enters to supply its place. If the apartment is heated by a fire, the circulation of the air will be increased. The size of the tubes should of course be proportioned to the size of the apartment to be ventilated.

249. There are some phenomena attending the passage of air through tubes, and its escape from them in certain circumstances, which are not a little curious. If a tube be made of tissue-paper, 6 or 8 inches long, and about an inch or a little less in diameter, having a piece of wood in one end with a hole in its centre a quarter of an inch in diameter, on blowing through this hole, either directly or by means of a small tube, the paper will collapse, plainly indicating the production of a partial vacuum within it. This we may suppose to be occasioned by the sudden expansion of the air on escaping from the small tube by which it was introduced within the paper tube. A portion of the air within the paper is blown away, and the tendency of the air outside to rush in and supply the vacuum, produces the collapse we have noticed.

It appears that the escape of a gas from a tube into the open air is always attended by a degree of rarefaction about the mouth of the tube, and a consequent pressure of the surrounding air towards this point at certain distances around. Let a person cut out two circular pieces of thick paper or pasteboard about 2½ or 3 inches in diameter, and, making a hole in the centre of one, insert in it the end of a small tube, as a quill; then, making the other disc of paper a little concave, let him place it with its concave side down upon the first, holding them in a horizontal position, with the quill downward. If now a strong current of air is passed through the quill by the mouth, contrary to what might be expected, it will be found quite impossible to blow off the upper piece of paper. The air blown through the quill expands and escapes at the edges of the paper discs, a partial vacuum being all the time kept up between them sufficient to keep the upper one in its place.

If the discs of paper are applied to the apparatus represented in figure 125, the same phenomenon it is said will be witnessed while the jet of water plays. The current of water issuing into the air produces to some extent the same effect as a current of air.

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blies are to remain some time in comparatively small rooms, what means should be provided for their ventilation? What occasions the deleterious air from the lungs to rise?

MACHINES FOR RAISING WATER—PUMPS.

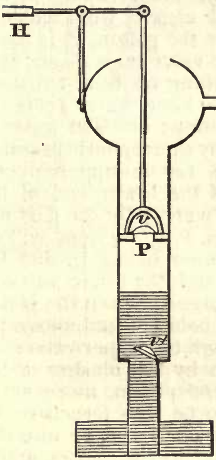

Fig. 121.

250. *Suction-Pump.*— Pumps for raising water are variously constructed, but the one most commonly seen is the suction-pump, so called from the peculiar mode of its action. This instrument is essentially the same as the air-pump already described (§ 220) except that it is made larger, and has much larger valves to permit the water to pass freely. It is worked by means of the handle, H, figure 121, and is usually a little enlarged at the top to form a reservoir for the water, and allow it to escape by the spout, S. When the lower part is immersed in water, and the handle worked, the first effect is to exhaust the air from the tube beneath the piston, P, precisely as in the air-pump; but this causes the water to rise gradually to fill the vacuum thus produced, until at length it reaches the lower valve, v', which is represented in the figure as open, the piston being supposed to be rising, and the valve v in it of course shut. After it has become filled with water, at every successive elevation of the piston, the water issues freely at S.

As the atmospheric pressure is sufficient only to raise a column of water to the height of about 33 or 34 feet, it will be seen at once that in this pump the lower valve must always be placed within this distance of the surface of the water; and it is therefore unsuited for use in deep wells, or in any case where the water is to be raised to a greater height than the distance mentioned.

Quest. 250. Is the common *suction-pump* similar to the air-pump in its construction? Why is it called by this name? When the lower part is placed in water, what is the effect of the first stroke raising the piston and upper valve? Why does the water rise? On depressing the piston, why does not the water again descend? After the water reaches the piston, how is it made to pass on through the pump? How high may water be raised by this pump? Why may it not be raised higher? How high may mercury be pumped?

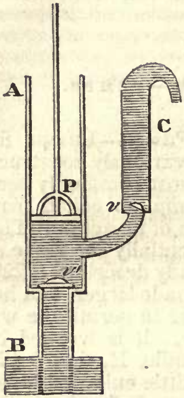

Fig. 122.

251. *Forcing-Pump.*—To avoid this difficulty the *forcing-pump* is sometimes used, by which water or any other liquid may be raised to any required height. Like the pump just described, it is formed of a cylindrical tube, A, figure 122, to which a smaller one, B, is usually attached, leading to the water of the well or cistern from which it is to be raised. But the piston, P, is made solid, and the upper valve, *v*, is placed in a tube or spout branching off from the main tube, A. At *v'* is the lower valve precisely as in the suction-pump; and the water is raised to this valve by atmospheric pressure just as in that pump. Let us suppose everything in order, and the lower end of the pump immersed in water; by the first elevation of the piston, P, a vacuum will be formed in the chamber below it, and the air will rush in through the lower valve *v'*, the water of course rising to supply its place. When the piston is again depressed, a portion of the air below it and above the lower valve, *v'*, will be forced out through the upper valve, but will be prevented from entering again by the closing of the valve. Upon a second elevation of the piston, more air is again drawn up through the valve *v'*, to be also forced up by the descent of the piston through the upper valve, *v*; and this is repeated until at length the water reaches the valves, and is made to pass through in the same manner as the air has done. At every elevation of the piston the water rises through the lower valve, and every time it is depressed, a portion is driven onward through the upper valve into the tube, C, by which the water may be raised to any required height. But though the height to which water may be raised by this pump is unlimited, yet, as it is raised to the lower valve by atmospheric pressure, this valve should never be placed farther than the oft-mentioned height of 33 or 34 feet above the surface of the water in the reservoir.

In this pump, as thus constructed, the water is necessarily forced out of the pipe, C, in successive jets, at every descent of the piston. In order to cause it to flow in a continued stream, an air-vessel is sometimes added to the lateral pipe, C, in the following manner:

Quest. 251. How is the *forcing-pump* constructed? Where is the upper valve placed? How is the water raised to the lower valve? Is there any limit to the height to which the water may be forced by this pump? In a pump constructed in this manner, how will the water be forced out? Why is this necessary? How may the water be made to flow in a continued stream? How does the air-vessel operate to produce this effect?

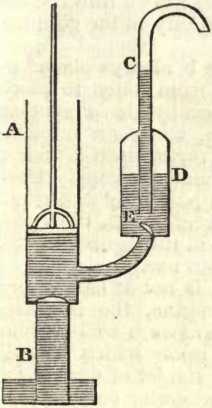

Fig. 123.

D, figure 123, is a strong vessel made perfectly air-tight, except the valve by which it connects with the body of the pump, and the tube C, which extends nearly to its bottom. Now, when the water is forced into this air-vessel through the valve at the bottom, the air contained in it is driven out through the tube, C, until the water reaches its lower extremity, E; but, as the surface rises above this point, all that remains must be condensed before it in the upper part of the vessel. In proportion as this air is thus condensed, and its elasticity increased, the water is made to rise in the tube, C; and will at length pour from it in nearly an equable stream, by reason of the uniform pressure of the condensed air in the air-vessel.

252. The *Fire-Engine*, as usually made, is merely a large forcing-pump of this construction, adapted to throw a stream of water to a great height for extinguishing fires. It generally has two cylinders, each with its piston and valves, so situated by the side of the air-vessel that the water from both is forced into it, one piston ascending and the other descending at each stroke.

A flexible leather tube called a hose, sometimes of one or two hundred feet in length, is attached to the pipe, C, by which the water may be carried to the immediate vicinity of the burning building, and directed to the proper points, without exposing the machine itself, or the men who work it, to danger or inconvenience from the heat. Let D E, figure 124, be a large box or reservoir to contain water; and let A and B be two cylinders with solid pistons; and C, an air-vessel, with a tube leading from near the bottom through its top. At V V′ V″ and V‴ are valves, the first and last opening upward, and each of the others opening into the air-vessel. If we now suppose the pistons to be worked by means of the handle to which they are connected, it will be readily

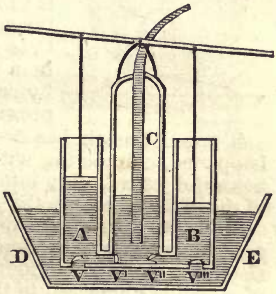

Fig. 124.

Quest. 252. What is the use of the *fire-engine?* What does it generally consist of? What is the use of the *hose?* Why are two forcing-pumps used? Is the water driven from both into the same air-chamber? Why is the fire-

seen that from both cylinders the water is forced into the air-vessel, from which it is driven by the elasticity of the confined air, in the manner described above.

The whole apparatus of the fire-engine is always placed on wheels, so as to be readily transferred from place to place, as necessity may require. There is generally also a suction-hose accompanying the machine, which, when an opportunity occurs, as is often the case, may be thrust into a well or cistern, and the instrument be thus made to supply itself with water just as the simple forcing-pump already described. This suction-hose is made to connect directly with the cylinders themselves, by means not indicated in the figure; so that the reservoir, D E, is not then brought into use.

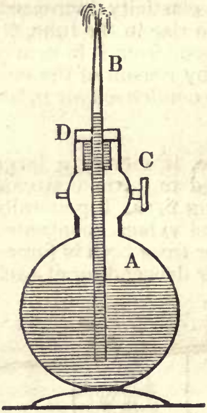

Fig. 125.

If a forcing-pump is not at hand, nor a model of the fire-engine, the following piece of apparatus answers well to illustrate the principle upon which the air-vessel acts to throw the jet of water. Let A, figure 125, be a globular vessel partly filled with water, having a tube, B, passing air-tight through the neck nearly to the bottom; after removing this tube, let the condensing syringe (§ 223) be screwed in its place, and a quantity of air forced in, which is done by unscrewing the cap, D, in which it is fixed. When the quantity of air forced in is sufficient, the faucet, C, is to be turned, the syringe removed, and the small tube, B, replaced; if the faucet, C, is now opened, the water gushes out in a beautiful jet of considerable height, by reason of the elasticity of the air compressed within.

If, when the air has been exhausted from a receiver, a tube is opened, connecting with its inside and a vessel of water, a beautiful jet will play into the receiver merely by the pressure of the atmosphere on the surface of the water without.

253. *The Lifting-Pump.* — The lifting-pump is designed to act altogether independently of atmospheric pressure. It consists of a hollow cylinder, A B C D, figure 126, the lower end of which is immersed in the reservoir from which the water is to be raised. At the proper distance, C D, from the bottom, a valve is placed opening upward, and below this is the piston

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engine placed on a carriage? Is a *suction-hose* sometimes connected with the engine? How may a jet of water be produced by means of a strong air-tight vessel and a condensing syringe? 253. How is the *lifting-pump* designed to act? What does it consist of? Where is the piston placed? How is it worked? Will this pump raise the water to any height?

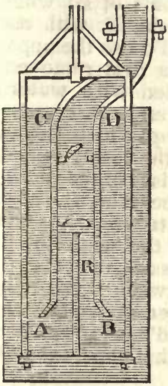

Fig. 126.

with a valve also opening upward; the piston-rod, R, passes down and connects with the frame-work, represented in the figure, by which it is worked. Above C D, the tube is bent so as not to interfere with it. This pump must be immersed so that the water may reach the upper valve; then when the piston is forced upward, the water above it is made to open that valve and occupy the pipe above C D, and on its descent is kept there by the closing of the valve, the water at the same time entering through the valve in the piston. On the reascent of the piston a portion of water is again forced up through the upper valve, and so on while the pump is worked.

254. We shall describe only one other pump, called the *double-acting pump*, which is represented in figure 127. A B is the cylinder in which the piston plays by means of a rod passing air-tight through a collar at A; and C, D, E and F are four valves, two of which will be open and two shut at each stroke of the piston. Let us suppose the piston to ascend, the water above it will be raised, causing it to open the valve, D, and pass on, as shown by the arrow, through the pipe leading to the cistern to which the water is to be conveyed; and, at the same time, by reason of the vacuum produced below the piston, it will rise through the valve, F, by the tube, H, leading to the reservoir below. When the piston is made to descend, the valves D and F will be instantly closed, and C and E opened, the water being forced through C by the piston, and drawn through E by atmospheric pressure. Pumps of this construction are used at the Fairmount water-works near Philadelphia, by which that city is supplied with water. They are worked by water-power.

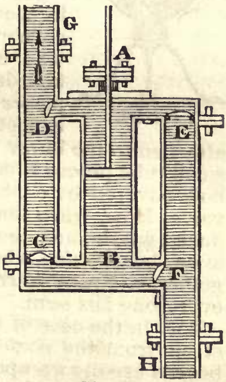

Fig. 127.

255. In the philosophical toy, called *Hiero's fountain*, a jet of water is produced by means of the pressure of a column of water acting on the air in an air-vessel. It is formed of two vessels, A and B, figure 128, which we will suppose made of glass, connected together by the tubes C and D, which pass air-tight through brass caps cemented upon the necks of the globular glass vessels. The tube, C, passes from the upper part

Quest. 255. How is the piece of apparatus called *Hiero's fountain* formed? By what means is the air compressed in the upper vessel so as to produce the jet?

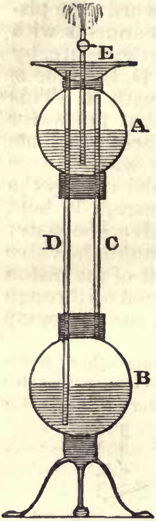

Fig. 128.

of the vessel, A, to the upper part of B; while the tube, D, connects the basin, E, with the lower part of the vessel, B. To use the apparatus, the small jet-pipe, E, is first removed, and the vessel, A, nearly filled with water; then the jet-pipe is replaced, and more water poured into the basin at the top, which passes at once by the tube, D, into the lower vessel, B. But, as soon as the water rises in the vessel, B, above the lower end of the tube, D, there being no passage for the air to escape, it will be condensed by the rise of the water in B, into the upper part of both vessels, the tube, C, forming a communication between them. By opening now the faucet, E, seen above the water in the basin, a beautiful jet d'eau is produced by the water issuing from the upper vessel through the central tube.

256. *Bellows.*—The various kinds of bellows in use are properly air-pumps for forcing this element in some particular direction or place. The common hand-bellows consists of two boards which are connected at their edges by pieces of leather carefully nailed all around, except a small space where the upper board is attached to the lower by a hinge; and from the same point a small tube proceeds called the nozle. In the lower board is a hole covered by a piece of thick leather, which constitutes a valve. Now, when the upper board is raised, a vacuum is produced within, and the air rushes in through the valve in the lower board; and when the two boards are again pressed together, a strong current is forced out through the nozle, as every one has seen.

257. In the case of the bellows described above, the current of air from the nozle is of course suspended every time the boards are drawn apart; but a continuous blast may be produced by introducing a third board with a valve between the two boards of the above bellows, the leather being nailed to the edges of the three boards. This constitutes the double or forge-bellows. It is in fact a double instrument. When the lower board is raised, the air within the lower bellows is forced into the upper through the valve in the middle board, and from this it is forced out in a continuous current by weights placed on the upper board. This bellows may be seen in constant use

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Quest. 256. What are the different kinds of *bellows?* How is the common hand-bellows constructed? How does the air enter when the instrument is opened? What is the effect produced when the boards are pressed together? 257. In these bellows, is a continuous current of air produced? How may the bellows be constructed so as to produce a continuous current?

in every blacksmith's shop; occasionally, though rarely, the form is modified; but the principle of action is always the same.

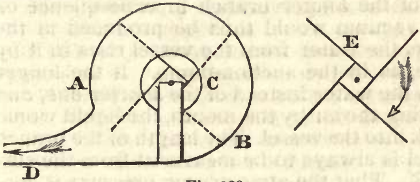

Fig. 129.

258. Within a few years past, the simple fan used in the common winnowing machine, so well known among farmers, has to a considerable extent superseded the bellows. A B D, figure 129, is a side-view of the instrument as generally used. It consists of a cylindrical box, usually not more than 3 or 4 feet in diameter, and from 1 to 2 feet in the other dimension. At C, is a circular aperture, from 8 to 12 inches in diameter, showing within the box a portion of the four fans and an end-view of the axis to which they are attached. E, is a side-view of the fans attached to the axis removed from the box. Now, suppose the fans in their place in the cylindric box are made to revolve rapidly in the direction indicated by the arrow at E, a strong current of air will be made to pass out through the aperture or tube, A D, a corresponding current at the same time passing in at C.

This instrument is now extensively used on board of steamboats that use anthracite coal for blowing their fires, and also in iron and other furnaces. In the common winnowing mill, as already remarked, it has long been employed.

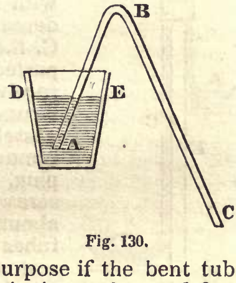

Fig. 130.

259. *The Syphon.* — This familiar hydraulic instrument, in its simplest form, consists of a bent tube, A B C, figure 130, having one of its branches longer than the other. If this tube be filled with water, and then closed by the finger to prevent its escape until the shorter branch can be immersed in a vessel of water, and held as represented in the figure, the liquid will immediately commence running, and will continue to flow until the vessel is exhausted. It will serve the same purpose if the bent tube is first immersed in the water, and the air then exhausted from it by applying the mouth at C.

Quest. 258. What instrument is now used to a considerable extent as a substitute for the bellows? What does it consist of? How is the current of air produced? What use is made of it on board of steamboats that burn anthracite coal? 258. Of what does the syphon consist? How is the tube to be filled at first?

260. To cause the flow of the water in the syphon, it is essential that one branch of the tube should be longer than the other; and the motion is always towards the longer branch. The water flows out of the longer branch in consequence of its weight; but as a vacuum would thus be produced in the upper part of the tube, the water from the vessel rises in it by atmospheric pressure, as in the suction-pump. If the longer leg were immersed in the water instead of the shorter one, and then filled by exhausting the air by the mouth, the liquid would immediately flow back into the vessel. The length of the branch immersed in the vessel is always to be measured from the surface of the water, D E. That the atmospheric pressure is concerned in the operation of the syphon is shown from the fact that it entirely fails to act in a vacuum; and also from the further fact that in the open air water refuses to pass a syphon-tube, the shorter leg of which exceeds 34 feet.

Large syphon-tubes have been used for practical purposes, for raising water many feet over obstacles that it would be difficult to remove; but the air which is always carried in with the water, being set free by the diminished pressure, rises to the highest part of the tube, and after a few hours accumulates so as to prevent the passage of the water. They are hence little used in practice.

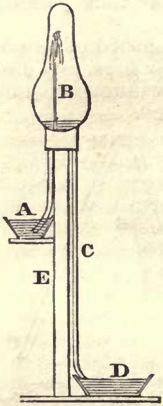

Fig. 131.

261. The manner in which the syphon acts is well illustrated when it is constructed with an air-vessel, as shown in figure 131, which is a section of the *syphon-fountain.* B is an air-vessel, supported by a pillar of wood, E, and having two tubes, A and C, connected with it, of which the first, A, may be considered the shorter branch of the syphon, and C, the longer. A is a vessel of water supported by a shelf; and D, a second vessel to receive it after being discharged from the instrument. To use the instrument, the air-vessel, B, with the tubes attached, is to be removed from its support, inverted, and the plug, in which the tubes are inserted, unscrewed. The air-vessel is then to be filled about a third full of water, the plug with the tubes screwed into its place, and the whole restored to the proper position upon the stand, E; immediately the water will begin to escape from B, by the tube, C, producing

Quest. 260. Must one branch of the tube always be longer than the other? In what direction does the water flow? How is it shown that the pressure of the atmosphere is necessary to cause the water to flow through the syphon? Why may not large syphons be used with advantage for practical purposes? 261. How is the *syphon-fountain* constructed? Is a partial vacuum produced in the air-vessel?

a vacuum within it, into which the fluid rises from the vessel, A, by atmospheric pressure. If the tube, C, is made considerably longer than A, with a bore also some larger, the jet of water on entering the air-vessel may easily be made to rise to a considerable height.

262. It is to be observed that the syphon must always be first filled with water before the current will flow, which may be done either by filling it with the two ends held upward and then suddenly changing it to its proper position, or by first placing it in this position and then exhausting it with the mouth or by means of an air-pump. The same effect obviously will be produced if the syphon is so placed with reference to the reservoir of water, that the fluid may rise around the shorter branch so as to fill it quite to the highest point; the water will then begin to be discharged through the longer branch, and will afterwards continue to flow, even though the surface of the water in the reservoir may fall.

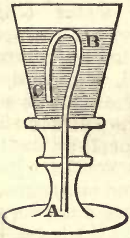

Fig. 132.

The philosophical toy called *Tantalus'-cup* is constructed on this principle. It consists of a cup, figure 132, with a syphon, C B A, in it, the short leg of which, C B, commences near the bottom in the inside; and the longer leg, B A, passes down through the bottom. Now, when water is poured in, it will rise in the shorter leg until it attains the highest point, B, in the syphon, when it will be discharged through the longer leg, and continue to flow until the surface is reduced to C. A small image of a man, supposed to represent the fabled Tantalus, (*see Article* TANTALUS, in *Anthon's Classical Dictionary*), is often placed over the syphon, so as entirely to conceal it; and, when water is poured into the vessel gradually, it rises until it nearly reaches the lips of the image, and then immediately subsides, without any cause being visible to the eye of the spectator. Sometimes the syphon is concealed in the handle of the vessel, but the effect is the same.

263. *Intermittent Springs.*— The phenomena of many *intermittent springs* may be explained on the principle of the syphon. Some of these springs ebb and flow alternately, and others have a periodical swell; a much greater quantity of water being discharged at one time than at another, the changes taking place at regular intervals.

Common springs are evidently merely the outlets of natural reservoirs of water which exist in every part of the earth, and

Quest. 262. What will be the effect if the water is made to rise around the shorter leg of the syphon until it reaches the highest part of the tube? How is the toy called *Tantalus'-cup* constructed? What is the effect when water is poured gradually into the vessel so as to raise the surface nearly to the mouth of the image? 263. What are *intermittent springs?* What are common

are filled by the water which falls upon the surface in rain and snow, and gradually percolates through the soil. When these reservoirs are near the surface, the supply of water sometimes ceases during long-continued droughts, and the springs of course become dry; but they are often situated so deep in the hills that no temporary cause of this kind can affect them, and they continue to flow at all times alike.

But, if the aperture or channel through which the water of the reservoir discharges itself, in some part of its course rises considerably above the bottom of the reservoir, a natural syphon may be formed, which will cause the spring constituting its outlet to exhibit an intermittent character.

Fig. 133.

Let A F, figure 133, be a section of part of a mountain containing a cavern, C, deeply-seated in it, and having an aperture or channel, D E F, leading from it to the valley or plain at its base. The water which falls in rain and snow upon the mountain in percolating through the soil, will find its way by natural fissures, as *m n*, to the cavern within, and gradually fill it, until the surface rises to the level *a a* of the highest point E in the aperture leading from it. A discharge will then take place from the spring, which, if the channel is sufficiently large, may be so rapid as gradually to reduce the quantity of water in the cavern, though the supply is continued; but, when the surface has fallen to the level, *b b*, the air from the cavern, C, will find admission into the passage, and the discharge of water will cease until the reservoir is again filled to the horizontal level, *a a*, as before. When this takes place, the passage will again be filled, and the spring again commence flowing.

If the part of the channel, E F, is of considerable length, water may drain directly into it from the soil in sufficient quantity to cause a small discharge of water from the spring while the cavern is filling, so that the flow may never entirely cease.

264. *The Diving-Bell.* — This is an instrument to enable persons to descend with safety beneath the surface of water. Though persons may with impunity descend unprotected a considerable depth in water, it is well known they can remain but a short time before they are obliged to come again to the

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springs? Why do these springs sometimes fail? Why do some springs appear to discharge very nearly the same quantity of water uninfluenced by the weather? How may a natural syphon be formed in the passage leading from the reservoir? Why in such a case would the water cease to flow at certain regular intervals? What may prevent the water from entirely ceasing to flow in some cases? 264. What is the design of the ***diving-bell***? Can

surface to receive a supply of fresh air. The longest period a person without much experience may remain under water with safety, is said to be only about half a minute; but, by long practice and painful exertion, one may at length become so accustomed to the effort as to be able to endure the deprivation of air it requires for two minutes. A few instances are on record, in which some of the pearl-fishers of the island of Ceylon have remained beneath the water four, five, or even six minutes; but such cases are exceedingly rare. But even this period is evidently too short for a person to perform any important operation about a sunken wreck, or in preparing to raise large articles that may be lying upon the bottom.

265. By the assistance of the diving-bell, persons are enabled to descend to great depths, and remain a considerable time. The diving-bell, in its simple form, is merely a large and strong vessel in the shape of an ordinary bell or receiver. It is usually made of metal; and if constructed of wood, it must be loaded with weights to cause it to sink.

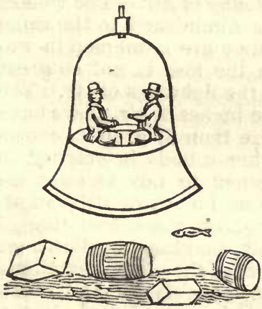

Fig. 134.

When a descent is to be made, the person places himself inside, as represented in figure 134, on a seat prepared for the purpose, and the attendants let the apparatus down in the water by means of a rope. As it descends, the air is condensed in the upper part by the pressure of the water; but a person within, it is found, experiences little if any inconvenience. When the bell nearly reaches the bottom, a signal is given by the person within to the attendants above by means of lines passing out under the edge, and the whole is retained in a fixed position, while exploration is made of the bottom within the circle of vision beneath. When it becomes necessary, the apparatus is drawn up, and its position changed. It is generally let down from on board a ship.

As will naturally be supposed, a person cannot remain a very great length of time below the surface, even in a diving-bell, by reason of the contamination of the small portion of air within by his breath. The vital principle of the air is rapidly absorbed by respiration; and if no new sup-

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persons unassisted remain for any considerable time under water? What is the longest period an inexperienced person can remain under water with safety? What length of time have pearl-fishers on the coast of Ceylon in a few instances remained under water? 265. What is the form of the diving-bell? What is it usually made of? Where does the person who is about to descend place himself? How are the persons within enabled to give signals to their attendants above the water? What effect is produced on the

ply of air is obtained, the person will in time as surely die in the diving-bell as if he was plunged directly into the water. To obviate this difficulty, an air-pump has sometimes been used, with a long pipe extending from it, by which fresh air from the surface may be forced down under the bell. Various contrivances have also been proposed at different times by which persons may be enabled to leave the chamber of the bell for a time to search the bottom in its vicinity.

By the use of the diving-bell, and apparatus connected with it, much valuable property that had been sunk in the sea has been recovered, which would otherwise have been totally lost.

It has recently been determined that a person diving from a bell, when at considerable depth, by reason of the *condensed* state of the air in the lungs, can remain much longer immersed in the water than when diving directly from the surface. If the bell is supposed to be at the depth of 34 feet, the volume of air within will be condensed to one-half its volume at the surface (§ 243), and of course the quantity in the lungs will be doubled, and capable of supporting the system twice as long as half the quantity, which is all that could be received in them at the surface, under the ordinary atmospheric pressure.

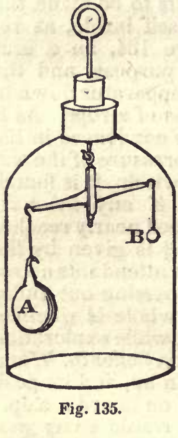

Fig. 135.

266. *Weight of Bodies in Air.*—The weight of bodies in air is diminished in the same manner as when they are immersed in water (§ 178), though the loss is not so great in consequence of the lightness of air. The weight of 100 cubic inches of air, as we have seen, is a little more than 31 grains; consequently, (§ 176), when a body is weighed in it, it will be sustained to this amount for every hundred cubic inches of its volume. That is, it will weigh so much less than it would in a vacuum, making no allowance for the trifling effect of the air in sustaining the weights themselves. Light and bulky substances of course lose much more in proportion than compact heavy ones. This is easily shown by means of a delicate balance. Let A, figure 135, be a hollow sphere of brass, which is just balanced by a solid sphere of lead, B, when in the open air; then placing them thus balanced under a large receiver, exhaust the air by means of the air-pump, and the larger body, A, will be seen to preponderate. The effect will be the same, if, instead of the hollow sphere, A, a piece of dry sponge, or a bunch of cotton or feathers, closely tied, be used. The reason is, that the larger body, displacing more air than the smaller, is sustained more by it than the smaller, and consequently it must

air in the bell as it descends? 266. Do bodies weigh less in the air than they would in a vacuum? What is the weight of 100 cubic inches of air? Will a body weighed in the air then lose 31 grains for every 100 cubic inches of its bulk? Do comparatively light or heavy bodies lose most in proportion

be really heavier in order that an equipoise may be produced in the air; and when the air is removed, the heavier body, being no longer supported, will of course preponderate. From this, it will be seen, the common method of weighing is not perfectly accurate, as it must always require more of light and bulky articles, as wool, feathers, &c., to make a pound, than it does of heavy substances, as the metals. A pound of feathers or cotton, therefore, as ordinarily weighed, must always be heavier than a pound of lead. In order that the pound of the two substances should be perfectly equal, it would be necessary that they should be counterpoised in a vacuum.

267. *Balloons.*—The balloon, or, as it is sometimes called, the air-balloon, is a kind of vessel designed for navigating the air. We have just seen that bodies in the air, by reason of its sustaining power, lose a part of their weight; and it is evident that, if a body of sufficient bulk in proportion to its weight could be obtained, it would rise in the air above the surface of the earth in the same manner as a piece of wood or other light substance will rise in water when held at a distance beneath the surface. But, unlike the piece of wood in water, a body of this kind could not rise and float upon the surface of the air because of its diminished density at great heights.

268. The method first adopted for constructing balloons was to obtain large vessels from which the air might be exhausted, and thus their weight diminished, while the bulk remained the same. It was supposed by the early experimenters that hollow spheres of copper might be made sufficiently light for this purpose; but it has been found by trial that vessels made in this manner must necessarily be so weak as to be crushed inward by the great pressure from without, as soon as the air within is exhausted.

The first ascent in a balloon was made by an individual in Paris in the year 1783, who rose to the height of 3000 feet, and descended again in safety. The machine which he used consisted of an immense elliptical bag, 74 feet long, and 48 feet in diameter, filled with heated air, to which was attached a kind of basket, made of wire, to contain the aeronaut. Under an aperture at the bottom of the bag an iron grate was suspended containing burning fuel to maintain the rarefaction.

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when weighed in the air? How may this be shown by experiment? As ordinarily weighed, is the pound of cotton or feathers, or the pound of lead heaviest? 267. What is the design of the balloon? What is necessary in order that a body may be made to rise in the air? 268. What was the method first adopted for constructing balloons? Can hollow spheres of metal be made so as to be at the same time sufficiently strong to resist the external pressure when exhausted, and sufficiently light for the purpose of a balloon? When was the first ascent made in a balloon? How was the balloon used on the occasion constructed? How may small balloons of paper easily be made to ascend? What will be the effect when the alcohol is consumed? Why is air when heated lighter than when cold?

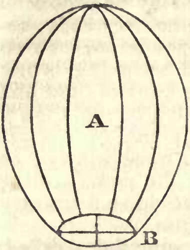

Fig. 136.

Small balloons made of paper may be easily caused to ascend to a considerable height by means of the rarefaction produced by burning alcohol. Let A, figure 136, be a spherical bag, 4 feet in diameter, made of tissue-paper, and having a circular opening at the lower side, B, 8 or 10 inches in diameter. In the centre of this opening, a piece of sponge, saturated with alcohol, is then to be attached by means of small wires, and the alcohol inflamed. As the air is heated by the flame, it expands and rises in the balloon, inflating it; and, when a sufficient quantity has accumulated, causing it to ascend in the air. When the alcohol is consumed, the air within the balloon is soon cooled, and it again descends to the surface.

The cause of the ascent of such a machine is easily understood. Air, when heated, as just intimated, is greatly expanded, so that a given bulk is much lighter than when cold; consequently, the balloon, with the sponge and alcohol, when filled with heated air, is lighter than the same bulk or volume of the surrounding cold air, and therefore rises through it.

269. Large balloons, designed to ascend any considerable distance above the surface, are now usually made of oiled silk, and inflated with hydrogen gas, which is admirably adapted for this purpose, being about 14 times lighter than air. It is indeed the lightest substance known in nature. (*For mode of preparing it, &c., see Author's Chemistry, page* 150.)

The balloon is made in a spherical form, of oiled silk, and to it the car, made as light as possible, is attached by numerous cords drawn over it, in order that the weight may be uniformly sustained by every part. Figure 137 represents a balloon inflated, with the car attached to it. A B is the balloon, with the network drawn over it to sustain the car; C, the car; and P D, the parachute, resembling a large umbrella. This last appendage makes no necessary part of the machine, but is usually added in order to prevent a too rapid descent of the car, should it by any accident, as sometimes happens, become detached from the balloon, or should any accident happen to the balloon itself. In one instance, the bal-

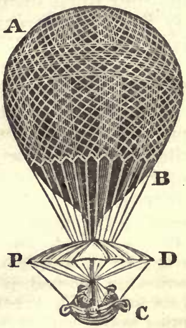

Fig. 137.

Quest. 269. What are large balloons now usually made of? With what are they inflated? Why is this substance selected? How much lighter is it than air? Of what form is the balloon made? How is the car attached to it? What is the *parachute?* What is its design? Have persons descended

loon being detached from the car at the height of 8000 feet, the aeronaut, by means of his parachute, descended in safety.

270. As the atmosphere diminishes in density above the surface, it is evident that a balloon which has considerable buoyancy near the surface, if its volume remains the same, will be capable of rising comparatively only a short distance; but, as the density of the atmosphere diminishes, the pressure diminishes also; and, as a necessary consequence, as the balloon rises, the gas within it expands. To prevent danger from the bursting of the balloon by this expansion, it is not fully inflated at first, but gradually becomes so as it ascends. A valve opening outward is also placed in the top to allow the gas to escape if the internal pressure becomes too great.

271. The greatest height to which balloons have been made to ascend does not exceed that of the highest mountains, or something less than 5 miles. At elevations much less than this, great cold is always experienced; and the effects of the diminished pressure upon the aeronaut becomes apparent by the quickening of the pulse, and parching of the throat, and swelling of the head.

Birds let fall from great heights, it is said, at first descend almost perpendicularly, their wings not being capable of sustaining them in a highly rarefied atmosphere.

The impossibility of guiding balloons has as yet prevented them from being made of any practical use; they can be made to move only before the wind, which does not always blow in the same direction, even at slight elevations above the surface, as it does at the surface. Hence, if the aeronaut delays until the wind at the surface is in the proper direction to make a desired passage, on ascending a little he may find it blowing towards a different point, so as to drive him far from his expected course. Individuals have, however, several times crossed the channel between England and France, but not without exposing themselves to great danger.

272. Attempts were made under Napoleon to render balloons useful in military operations, by enabling a sentinel to view the position and movements of the hostile army from an elevated position. When used for this purpose, the balloon was inflated and secured to the ground by a rope at such an elevation as was desired, and signals made by the observer to the officers below. At the battle of Fleury, a French general ascended in this manner to the height of nearly 1500 feet; and it has been said that the information he was able to communicate to his commanding officer, general Jourdan, by means of signals, decided the fate of the contest.

273. Instead of hydrogen, the gas prepared from bituminous coal, or from resinous or oily substances, and used for illuminating purposes in most large cities, is now often used for inflating balloons, in consequence of its cheapness. Though much lighter than air, it is considerably heavier than hydrogen; and balloons in which it is to be used, in order to ascend with the same force, must be made larger than those designed for hydrogen gas. (*For method of calculating the buoyancy of a balloon, see Author's Chemistry, page* 154.)

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in safety from great heights by means of the parachute alone? 271. What has prevented balloons from being made of any practical use? Does the wind always blow in the same direction above the surface, as it does at the surface?

274. *The Steam-Engine.*—The steam-engine is a machine for producing motion by the elastic force of steam from boiling water. Though it is an instrument of great power, its invention is comparatively very recent; indeed, it has only been brought to a state of perfection (if so much can even now be said of it) within the last few years.

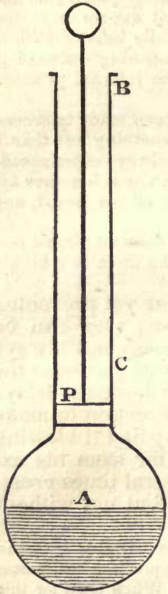

Fig. 138.

Water boils, or is converted into steam, as is well known, whenever it is heated to 212° of Fahrenheit's thermometer; and the steam formed from any given quantity of water occupies 1696 times as much space as the water itself. Consequently, if a vessel capable of being closed air-tight be nearly filled with water, and heat applied so as to convert it into steam, it will fill the whole vessel, and unless it is very strong, will burst it outward. If a small orifice is made above the surface of the water within for its escape into the air, a jet of steam will issue from it with great force. If to this orifice a cylindrical tube is attached, containing a solid piston and rod, the piston will be forced out before the steam, carrying with it whatever may be attached to the rod. This may be illustrated by figure 138. A B C is a large glass flask or matrass, having a long cylindrical neck, B C, of as equal a diameter in every part of its length as possible. The bulb or body of the vessel, A, is to be partly filled with water, and the piston, P, inserted by means of the rod and handle attached to it. If now a lamp is placed under A, the water will soon be made to boil, and sufficient steam be formed to force up the piston quite to the top of the tube. But, if the lamp is removed, no more steam will be formed; and that within will soon begin to be condensed into water by the cold air surrounding the outside of the vessel, producing a vacuum, and leaving the piston to be forced down again by the pressure of the atmosphere. If a little cold water is sprinkled upon the bulb, A, above the water, the steam will be condensed much sooner, and the piston of course descend

Quest. 274. What is the *steam-engine?* Is its invention of recent date? At what temperature does water boil? How many times is the bulk of water expanded in changing into steam? How may steam be made to issue from a vessel with great force? If a straight tube containing a solid piston is connected with the vessel of boiling water, what will be the effect? How is this illustrated by figure 138? What will be the effect if the lamp is removed? What will be the effect of sprinkling a little cold water upon the vessel above the surface of the water? How may the piston be made to rise again?

more rapidly. By applying the lamp again, the piston may of course be forced up as before.

275. In order to understand this fully, it is necessary only to observe that, as water is converted into steam by raising its temperature to 212 degrees, so, if steam already formed has its temperature reduced below this point, it will be again converted into water; and if, in the first instance, its volume was increased 1696 times, so also in the second it must be diminished in the same ratio.

In this simple apparatus, A may be considered the boiler, and the tube, B C, the cylinder, as these terms are used in reference to the steam-engine.

It is very evident that an engine constructed after this model would accomplish but little, as its motion must necessarily be slow, the piston being urged in one direction only by the steam, and in the other direction by atmospheric pressure. In the steam-engine, as now used, the steam is let into the cylinder on both sides of the piston, its action being entirely independent of atmospheric pressure.

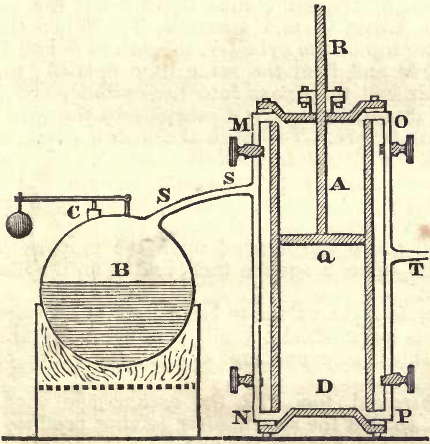

Fig. 139.

276. There are two kinds of the steam-engine, the high-pressure engine, as it is called, and the low-pressure engine. We will first give an explanation of the essential parts of the former, or high-pressure engine. As the machine, with all its appendages, is necessarily very complex, we shall find it for our advantage to confine our attention exclusively to the parts necessary to produce motion, arranged not as they are found in working engines, but in such a manner that they can be conveniently represented on paper. Figure 139 is designed to represent a section of a boiler, and cylinder with its piston, steam-pipes,

Quest. 275. What effect is produced upon steam if cooled below 212°? What part of the apparatus, figure 138, may be considered the boiler, and what the cylinder? Would an engine constructed after the above model be effective? 276. What two kinds of the steam-engine are there? In figure 139, what is the boiler, and what the cylinder and piston? How are the

and valves. B is a section of the boiler partly filled with water; A D the cylinder; Q the piston; R with the rod which plays through the collar, so as to be steam-tight. A steam-pipe, S, passes from the upper part of the boiler, and branching into two parts, connects with the cylinder at the top and bottom. Another pipe is placed on the opposite side of the cylinder, connecting also with it at the top and bottom, called the escape-pipe, having an opening at T. M N O and P are valves which, for our purpose, we will suppose to be opened and shut by the hand, as occasion may require. C is a safety-valve, which is kept closed by a weight attached to a lever. It is designed to prevent danger by the bursting of the boiler from a too great accumulation of steam within. When the pressure has increased to a certain point, this valve is lifted by it, and the steam makes its escape.

277. Now, suppose the fire to be kindled under the boiler, and the space above the water filled with steam, which will find its way along the steam-pipe to the valves M and N; if the valves N and O are now opened simultaneously, the steam will rush into the lower part of the cylinder, and by its elastic force raise the piston, at the same time driving out the air above it through the valve, O, and aperture, T. When the piston has reached the top of the cylinder, the valves N and O are to be closed, and M and P at the same time opened; the steam from the boiler will then pass into the cylinder above the piston, forcing it down, that below it escaping by the valve, P, and aperture, T, as before. To cause the piston again to ascend, the valves, M and P are to be closed, and N and O at the same time opened; thus, a reciprocating motion of the piston is produced through the length of the cylinder, by opening and closing two valves at each stroke. The force with which the piston will move will depend upon the amount of pressure of the steam upon a square inch, and upon the diameter of the cylinder.

We have here supposed the valves to be opened and closed by hand—and this was the method actually adopted in the first steam-engines—but this is now accomplished by the action of the machinery itself.

278. It will be observed, too, that the escape-pipe opens directly into the air, so that the steam, after having produced its effect, is forced out at T, against the pressure of the atmosphere. Consequently, the pressure of the steam in the boiler, in order to move the piston, must be more than equivalent to

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boiler and cylinder connected? Why does this pipe branch into two parts? What is the escape-pipe? What is the design of the safety-valve? 277. Supposing the steam to be raised, how may the piston be forced up to the upper part of the cylinder? How may it be again forced down? What now is necessary to give the piston a constant reciprocating motion? Are the valves always opened and closed by hand? 278. Into what does the steam escape in this engine? Must the pressure of the steam in the boiler, there-

the ordinary atmospheric pressure; hence, an engine of this construction is called a *high-pressure engine*, in contradistinction from the *low-pressure engine*, in which the escape-pipe opens into a vessel of cold water called the condenser, as will shortly be described.

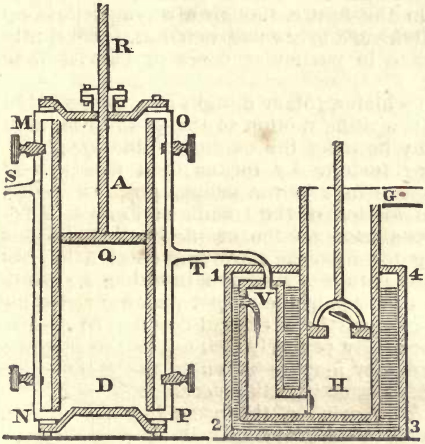

Fig. 140.

279. Figure 140 is a section of the cylinder, condenser, air-pump, &c., of a low-pressure steam-engine. All the parts immediately connected with the cylinder are precisely the same as in the high-pressure engine; but the escape-pipe at T, instead of opening into the air, enters a large cistern 1, 2, 3, 4, which is kept filled with cold water, and is there considerably enlarged. G H is an air-pump, connected with the escape-pipe by a large tube and valve. At V is a short tube with a faucet by which water is admitted from the cistern to condense the steam as it enters from the escape-pipe, T. As a vacuum is always kept up in the condenser by the air-pump, the cold water will of course rush in by atmospheric pressure.

It will now be easy for the intelligent student to understand the construction and the mode of action of this engine, and in what it differs from the high-pressure engine. The air-pump is worked by the engine itself; it is called an air-pump because the design of it is to keep up a vacuum in the condenser by exhausting the air at first contained in it, and any that may enter with the steam or with the water from the injection-pipe V. It also removes the water that enters by the injection-pipe, which is allowed to escape by the pipe at G.

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fore, be always greater than the ordinary pressure of the atmosphere? Into what does the steam escape in the *low-pressure* engine? What is the essential difference between the *high* and *low* pressure engine? 279. Are the boiler, cylinder, piston, &c., the same in both the high and low pressure engines? Into what does the escape-pipe lead in figure 140? What is the use of the air-pump in this engine? How is the water made to enter the condenser? How is the air-pump worked? How is the water removed from the condenser?

280. There are in the perfect engine several other parts not here represented, as a cold-water pump, to keep the cistern 1, 2, 3, 4, constantly supplied; and also a hot-water pump, which takes a portion of the water that has passed through the condenser, and forces it into the boiler, in which the water must be kept at nearly a uniform height. These parts, as well as those represented in the figure, though always performing the same office, are often variously constructed and differently situated, as convenience in particular cases or caprice may dictate.

281. The manner in which a rotary motion is communicated to a wheel by the reciprocating motion of the piston-rod, may be readily conceived by noticing the common itinerant knife-grinder turning his grindstone by means of a treadle and crank. Putting the stone first in the proper position by the hand, by a downward motion of the treadle and crank, it begins to revolve; and as soon as the crank has reached its lowest point, by lifting the foot, the revolving motion is continued by the mere momentum of the parts until half a revolution is made, and the crank is in the proper position again for a new impulse to be given it by a second downward motion of the treadle, as before. By properly managing the motions of the foot, a great velocity may be given to the stone, even though considerable resistance is to be overcome.

In the case of the knife-grinder, the propelling power can have but a single downward motion, and can act only through half a revolution of the stone; but if, instead of the foot, a rod is used, attached by a hinge-joint to the piston-rod of a steam-engine, an impulse can be given both upward and downward, by which a much greater resistance can be overcome, and steadiness of motion secured. There must, however, always be two points, called the *dead-points*, by which the revolutions must be continued by the momentum of the machinery. To ensure steadiness of motion in every part of a revolution of the crank, a large heavy wheel, called a *fly-wheel*, is often attached, especially in small engines, in which the parts of the engine itself have but a small momentum.

For a more full description of this instrument of human power, the reader is referred to larger works devoted to the subject, especially Professor Renwick's recent lucid treatise on the Steam-Engine.

Quest. 280. What is the use of the cold-water pump? What is the use of the hot-water pump? Are the parts of the engine described always constructed in the same manner? 281. How is a rotary motion produced by means of the engine which gives directly only a reciprocating motion backward and forward? How does the knife-grinder turn his grindstone by means of a treadle? In the case of the knife-grinder, does the propelling power act in more than one direction? In the steam-engine, in what directions is the impulse given? What is the use of the *fly-wheel*?

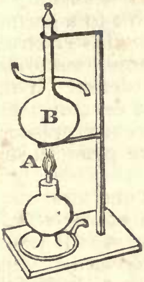

Fig. 141.

282. The *Rotary Steam-Engine*, which has been used with some success, acts on a principle entirely different from the preceding. It has been constructed in different modes, but the principle of its action may be understood from figure 141, which represents a toy made by common glass-blowers. B is a globular vessel of thin glass, which rests upon a pivot, A, and is supported by a stand. From opposite sides of the vessel, at its upper part, two tubes proceed, and near their extremities are bent nearly at right-angles in opposite directions. If, now, a little water is poured into the vessel, and heat applied by means of a lamp, the steam, as it is formed, on escaping from the tubes, will give it a rapid rotatory motion. The steam, as it issues from the tube, meets with resistance from the air; but the current, being urged on by the pressure within, puts the tube in motion in the opposite direction. A current of water issuing from an orifice produces the same effect; and it is on this principle that Barker's centrifugal mill is constructed.

Rockets are propelled through the air by means of a current of heated gas issuing in this manner from a tube. A kind of gun-powder (if it is proper so to call it) is made, that burns much slower than that usually seen; and a tube of strong paper is filled with it, and one end inflamed; and the rocket shoots rapidly into the air by means of the current of heated gas that is produced and rushes out from the tube. A long slender stick is usually attached to it, to direct it in its course.

283. *Meteorology.*—Meteorology is the branch of science which treats of the various phenomena of the atmosphere, as heat, cold, rain, snow, hail, clouds, winds, &c. The temperature of the atmosphere is exceedingly different in different parts, even though in the immediate vicinity of each other. As a general rule, admitting of few exceptions, the strata nearest the earth are warmest; and, as we ascend, a gradual reduction of temperature is observed to the highest point that has been attained by man. The reason of this probably is in part because the air receives its heat chiefly if not wholly from the earth; the rays from the sun pass through it, as they do through glass or other transparent media, without affecting its temperature; but, being received and absorbed by the earth, a portion is again imparted to the atmosphere, of course heating its lower strata first. Another cause is found in the fact, that, as any portion of air ascends above the surface, a great expansion takes place by reason of the diminished pressure to which it is subject; and this it is well known is always attended by a reduction of temperature. As the strata near the earth are warmer than those above, it might be expected that they

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Quest. 283. What is *meteorology?* Is the temperature of the atmosphere the same in every part? From what does the air chiefly receive its heat? Do the rays of heat from the sun generally pass through transparent bodies without heating them? How is the temperature of a portion of air affected as it rises above the surface? When the air near the surface becomes heated,

would rise and give place to the colder portions, according to the general law of fluids in such cases*—and this to a certain extent undoubtedly does take place—but while the lower strata are warmer than those above, they are at the same time under greater pressure, and may therefore be more dense. If the temperature of the lower strata is raised above a certain point, they become so rarefied, notwithstanding the greater pressure to which they are subjected, as to rise and give place to surrounding colder portions.

As the cold increases in proportion as we ascend above the surface, it is evident a point may be attained, above which, even on the equator, ice and frost will remain during the whole year. This is called the altitude of *perpetual congelation*. This is found by observation to be on the equator about 15,600 feet above the level of the sea; at 20 degrees from the equator it takes place at the height of a little more than 13,700 feet; and 45 degrees from the equator at about 7658 feet; while at the poles, and indeed at some distance from them, ice remains during the year upon the surface of the sea.

But it is often found that different strata of air, immediately adjacent to each other, are at very different temperatures. Thus, the aeronaut in ascending, often passes suddenly from a warm to a very cold region, where snow and hail are forming; but, on rising higher, it becomes warmer again. This, no doubt, is occasioned by local currents in the atmosphere, by which portions of the air of different latitudes, and perhaps distant places, are brought into the immediate vicinity of each other.

284. Wind is moving air, and is occasioned generally, it is supposed, by changes of temperature in different regions of the atmosphere. When the air in a particular district becomes heated above that in surrounding parts, it rises, and the colder air in the vicinity rushes in to supply its place. This is well illustrated by the phenomena attending the kindling of a large fire in the open air in calm weather. By passing around the fire, it will be observed that the wind blows towards it on every side; while above it a current sets upward with so much

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will it always rise and give place to surrounding colder portions? How does the temperature change as we ascend from the surface? What is meant by the altitude of *perpetual congelation*? What is this altitude on the equator? What is it at 20 degrees from the equator? What is it at the distance of 45 degrees? And what at the poles? Are the strata of air immediately adjacent to each other at different temperatures? What is often observed by the aeronaut as he ascends in his balloon through different strata of the air? How may the occurrence of different strata in this manner be accounted for? 284. What is wind? How is the motion of the air occasioned? What effect is produced when the air in a particular district becomes heated above that of surrounding regions? How is this illustrated?

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* See Author's Chemistry, page 20.

force that fragments of the burning materials are often carried up to considerable heights. The accidental burning of a building in a calm evening sometimes affords an opportunity of witnessing these effects in the most striking manner.

285. The rise of smoke in a chimney, and the current of air produced in the pipe leading from a stove, are dependent upon the same cause. The air being heated by the fire and expanded, becomes lighter than the surrounding atmosphere, and therefore rises often with considerable force. Before a fire, near the floor, a current will always be found setting towards the fire to supply the place of that which is constantly ascending in the chimney. The same will be observed of the air in front of a stove; but only a slight current will in this case be discovered, since the quantity of air that passes up the chimney is much less than when an open fireplace is used. We see therefore why the same quantity of fuel will heat a room much more when burned in a close stove than when an open fireplace is used; in the latter case no more air is allowed to enter the stove and pass up the chimney than is necessary for the combustion of the fuel; but when an open fireplace is used, much heated air from the room escapes with the gases and smoke produced by the combustion. Of course as much of cold air must always enter a room as there is of warm air that escapes; and thus a large proportion of the fuel is expended to no useful purpose.

We see here, too, why the chimney of a new close room is likely to smoke. In order that a strong current may be formed in the chimney, it is evident a good supply of air must be admitted from without; but, if this is prevented by the closeness of the room, the current in the chimney cannot be formed, and as a necessary consequence, the smoke, instead of passing out by the chimney, rises in the room. When this is the case, a perfect remedy is usually found in opening some door of the apartment by which a good supply of air is admitted.

286. The land and sea breezes which daily occur on the coast and in the islands of the tropical regions, are produced in a similar manner, but on an immensely larger scale. In some of the West India islands they occur with great regularity. About 9 o'clock, A. M., the wind begins to blow from the sea

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Quest. 285. What occasions the rise of the smoke in a chimney and the pipe of a stove? In what direction does the air move near the floor before an open fire in a room? Is the current as perceptible before a close stove? What is the reason? Why will not the burning of a given quantity of fuel in an open fireplace heat a room as much as if it were burned in a close stove? How is the place of the air supplied that escapes through the chimney? Why is the chimney of a new close room likely to smoke? Why is the difficulty remedied usually by opening a door? 286. How are the land and sea breezes of the West Indies and other tropical climates produced? At what hours do these breezes commence? How are these winds accounted

towards the land on every side of the island, and continues until evening, when after a period of calm it commences to blow from the land in all directions towards the sea. The former is called the sea, and the latter the land-breeze. They are occasioned by the unequal effect of the sun's rays on the land and water, the latter being heated or cooled much less readily than the former. The action of the sun's rays in the morning soon raises the temperature of the land above that of the neighbouring ocean; and a portion of the heat being communicated to the air above it causes it to ascend as before explained, and the air from the surrounding water rushing in to supply its place, produces the regular sea-breeze. After sunset, the land (with the air above it) cooling more rapidly than the water, the latter soon becomes warmest, and a current of air is established in the opposite direction from that in the morning, or from the land towards the sea, which constitutes the land-breeze.

287. In some parts of the Indian Ocean, from November to March, the wind generally blows from the north-east to the south-west; and from March to November in the opposite direction, from south-west to north-east. These winds are called *monsoons;* their cause is not well understood, but no doubt it is in part at least to be attributed to the unequal distribution of the sun's heat over the surface during the different seasons of the year. It will be observed that the general direction of the wind is from the north of the equator towards the south, during that part of the year in which the heating influence of the sun's rays is greatest at the south; and in the opposite direction during the part of the year when the sun's heat is greatest at the north. This would seem to indicate that the rarefying influence of the sun's rays is a great, though not perhaps the *sole* cause of the phenomenon.

288. The same cause, it is very well ascertained, produces the *trade-winds*, which blow constantly from a general easterly direction some 28 or 30 degrees north and south from the equator in the Atlantic and Pacific Oceans. North of the equator they are found to vary from the east to the north-east, and in like manner, south of the equator, their general direction is from the south-east; but in both hemispheres they are subject to some variation, according to the season of the year, and are affected often by the proximity of land. By the diurnal motion of the earth, those parts of its surface exposed to the sun's

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for? Why is the air over the land heated and cooled more readily than that over the water? 287. Where do the winds called the *monsoons* occur? In what directions do they blow from March to November, and from November to March? To what are these winds, in part at least, to be attributed? 288. In what direction do the *trade-winds* constantly blow? North of the equator, in what direction do they vary? In what direction do they vary south of the equator? Are they modified by the proximity of land? In what

more direct rays become heated above the adjacent parts, producing a disturbance in the equilibrium of the air above them, in the same manner as already pointed out. As the point of greatest heat is constantly progressing west with great rapidity, it is followed by a current of air setting towards it, though, as we should expect, on the north of the equator, inclining more or less from the northward, and on the south of the equator, from the southward. Above the regions where the trade-winds prevail, it has been very satisfactorily ascertained, there are currents of air in the opposite directions from the winds at the surface; that is, while the currents of air at the surface move in a general direction from east to west, in the upper regions of the atmosphere they are moving in a general direction from west to east. Thus, when volcanic eruptions have occurred in some of the West India islands, ashes thrown out have been known to fall far to the eastward, though the wind at the surface all the time was blowing from that direction.

The trade-winds north and south of the equator do not meet, as might be supposed; but there is a space of some 200 or 300 miles between them, called the region of calms, where there is seldom any wind. This fact entirely refutes the notion which formerly prevailed, that these winds are occasioned merely by the motion of the earth on its axis; as the atmosphere, though it partakes of the motion of the earth, might be supposed to move less rapidly than the earth, and therefore, to persons on the surface, have the appearance of moving in the contrary direction, or from east to west. On this supposition, it is evident the wind should be strongest at the equator, where the motion of the earth is greatest, contrary to what has just been shown to be the fact.

289. *Whirlwinds* are violent movements of the atmosphere, in a circular or spiral direction about an axis, the whole having at the same time a progressive motion. They occur chiefly in the tropical regions, but extend also into the temperate zones. Sometimes they are of very limited extent; at others they extend over a portion of the surface included in a circle of several hundred miles in diameter. They then constitute the *tornados* of the Atlantic ocean and West Indies, and *typhoons* of the Chinese sea. In the western part of the Atlantic ocean, it is found, they usually commence in the vicinity of the West Indies, and progress, with greater or less rapidity, along the

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direction does the point on the surface of the earth, when the heating influence of the sun's rays is greatest, constantly move? In what direction do the currents of air move in the upper regions of the atmosphere in those parts of the earth where the trade-winds prevail? How has this been ascertained? Do the trade-winds blow at the equator? May the constant easterly direction of the winds between the tropics be occasioned by the diurnal motion of the earth? On this supposition, where should the trade-winds be strongest? 289. What are *whirlwinds?* Where do they chiefly occur? What is said of their extent? What are *tornados?* What are they called when they occur in the Chinese sea? Where is it found they usually commence in the

coast of the United States, towards the north, until they are dissipated or lost in high northern latitudes. North of the equator, the whirl, it is believed, is always in the direction of the points of the compass, N. W. S. and E.; while south of the equator they are in the opposite direction, or from N. through the E. S. and W.

290. The atmosphere, it is well known, even when dryest, always contains in it a portion of watery vapour, from which dew, fog, clouds, rain, snow, hail, &c., are formed. This vapour is constantly rising from the surface at every temperature, but its formation is much the most rapid in warm weather, and the atmosphere then contains the most moisture. Its presence is shown whenever a pitcher is filled with cold spring-water, and allowed to stand a short time, by the dew which forms upon its surface, and at length trickles down the sides in large drops.

When a portion of air near the surface charged with moisture is suddenly cooled, the water it contains is condensed, and becomes visible, producing *fog* and *mist*. When the condensation takes place in the upper regions of the atmosphere, it forms clouds. These often remain freely suspended in the air without apparent change, but if a rise of temperature occurs, they gradually disappear, the particles being again dissolved in the air. When, on the other hand, the condensation is continued to a certain point, the drops of water fall to the ground, constituting *rain*. If the cold is sufficient to freeze water in that part of the atmosphere where the condensation is taking place, *snow* is produced, and falls in feather-like crystals.

In that part of the United States on the coast of the Atlantic Ocean, it is well known that the snow-storms usually come from the south-west, commencing earlier at Philadelphia than at New York, and earlier at this place than at Boston, &c.; though the wind all the time is at the north-east. It is evident, therefore, that in the upper regions of the atmosphere, there is a current of warm air, moving from the south-west to the north-east, whilst at the surface a current of cold air from the north-east is moving in the opposite direction. Now, supposing the warm air from the south to be highly charged with moisture, as it no doubt in such cases is, we have all the conditions

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western part of the Atlantic ocean? In what direction do they then progress? In what direction is the whirl north of the equator? South of the equator? 290. What is always contained in the atmosphere? What are formed from this vapour? From what is this vapour formed? During what season is it produced most rapidly? How may the presence of this vapour be shown in warm weather? How is fog produced? What is mist? How are *clouds* formed? What may often occasion the disappearance of clouds that have remained a time suspended in the air? How is *rain* produced? How is *snow* produced? In what part of the United States bordering on the Atlantic ocean is it observed that snow-storms usually first commence? In what direction does the wind usually blow during these storms? What must be the direction of the wind in the higher parts of the atmosphere? How will

necessary for the production of snow. The moisture of the warm air, in mixing with colder current from the north, is not only condensed but frozen, and falls to the earth as snow, in accordance with our principles.

291. *Hail* is produced by the freezing of the drops after they are formed, by their passing through cold strata of the atmosphere, in the course of their descent. In some few instances which have been recorded, hail-stones of enormous size have fallen, even several inches in diameter,—a fact which seems to indicate that a rapid accumulation must have taken place during their descent, from the moisture contained in the atmosphere.

Fig. 142.

292. The *rain-gauge* is an instrument for measuring the quantity of water which falls in the form of rain, hail, &c, in a given time in any place. This quantity is usually estimated in inches; and when it is said that an inch of rain has fallen, the meaning is that if the surface of the earth were perfectly level, the water which has fallen at the time supposed would be sufficient to cover it an inch deep.

There are several varieties of the rain-gauge, but one of the following construction answers the purpose well, and is convenient to use. A B, figure 142, is a glass tube an inch in diameter, and from 2 to 3 feet in length, and has cemented upon it at the top a metallic vessel or funnel, C, the mouth of which is four times that of the tube itself; consequently, an inch of water in the funnel must fill the tube four inches. By the side of the tube a scale is attached graduated into inches and proportional parts, which, however, are made four times as long as the common inch. Now, as the mouth of the funnel is four times that of the tube, an inch of rain falling into the funnel will fill the tube four inches, or just one of our divisions.

To determine the quantity of rain which falls, the instrument is to be attached to an upright post, and placed at a distance from any building, so that even in windy weather the rain shall fall freely into it. Snow and hail are to be caught in a vessel, the mouth of which is of the same size as that of the rain-gauge; and after it is melted, the quantity of water is to be determined by pouring it into the gauge.

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the mingling of two such currents produce the results which are witnessed? 291. How is hail formed? Do the hail-stones probably increase during their fall? 292. What is the design of the *rain-gauge?* What is meant when it is said an inch of rain has fallen? How is the rain-gauge, represented in figure 142, constructed? How much larger is the mouth of the tube than the tube itself? How high does an inch of rain fill the tube? Will the quantity of rain that falls in windy weather be accurately indicated?

CHAPTER IV.

ACOUSTICS.

293. Acoustics is the science of sound, and has for its appropriate object everything which affects the organs of hearing.

Sound is the result of a vibratory motion produced in the air or some other elastic body. Usually, whatever may be the body in which this vibratory motion is first produced, it is conveyed to the ear by means of the air.

294. When these vibrations take place in a uniform, regular manner, a perfect sound or *tone* is produced; but if the vibrations are irregular and interrupted, a mere *noise* results.

Fig. 143.

The vibration of a sounding body may often be seen by the eye, as in the case of the lower strings of the violoncello, or the prongs of the common tuning-fork. The form of this last instrument is seen in figure 143. When it is held by the handle, and the two prongs pressed together and suddenly released, or one of them struck against some solid substance, a distinct sound is heard; and by close inspection the prongs may be seen in rapid vibration to and from each other, as indicated by the dotted lines. The particles of dust or sand upon a bell, when it is struck, are observed to be put in rapid motion.

295. Sound is conveyed from the vibrating body to the ear by means of vibrations in the air, as already stated; hence, if a bell is placed under the receiver of an air-pump, as the air is exhausted its sound becomes less and less distinct, until it can scarcely be heard. If the air be now gradually readmitted, and the bell in the mean time rung, the sound will be observed to increase in intensity in proportion as the density of the air in the receiver increases.

Quest. 293. What is the object of the science of acoustics? What is sound the result of? How are sounds conveyed to the ear? 294. What is the result when the vibrations are regular? and what when they are irregular and interrupted? May the vibrations of the sounding body be sometimes seen by the eye? What is the form of the tuning-fork? 295. What is the effect if a bell be struck several times as the air is exhausted from a receiver under which it is placed? What will be the effect as the air is again admitted? How is a bell made to ring under an exhausted receiver?

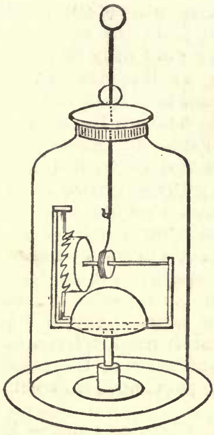

Fig. 144.

Figure 144 represents an apparatus which is used for this purpose. It is so constructed that by pulling the rod upward, which passes air-tight through the neck of the receiver, the small bell is made to ring without admitting the air. The apparatus must not be allowed to touch the receiver, nor should it stand directly upon the plate of the air-pump, as the vibrations will then be partially communicated through the solids to the external air, and thence to the ear. A piece of sheet India-rubber answers well to insulate it from the plate of the pump.

296. Sounds are less intense on high mountains than in the valleys below, in consequence of the diminished density of the atmosphere. This would be expected from the experiment just described; yet the explosions of meteors at vast elevations have often been heard. In condensed air sounds become more intense; an increased loudness of the voice is always observed by persons descending beneath the surface of the sea in diving-bells (§ 265), where the density of the air is greatly increased by the pressure of the water.

297. In comparing different sounds, the ear readily distinguishes three peculiarities, viz: *intensity* or *loudness*, *pitch*, and *quality*, called by the French *timbre*. The difference of sounds in intensity or loudness depends upon the greater or less extent of the vibrations, and are readily perceived by every one; but variations of pitch are not so easily recognised, at least by the uneducated ear. In music, differences of pitch are designated by the terms high and low, sharp and flat, acute and grave. But sounds precisely alike in intensity and pitch may yet differ in a third respect, which, for want of another term, we have called *quality*. Thus, a wire extended over a table made of pine wood will give a different sound from another extended over an oak table, though both are at the same pitch, and are alike as it regards intensity. So the sound of a flute and that of a violin, when playing the same tune, are entirely unlike as it respects this peculiarity.

Quest. 296. Why are sounds less intense on high mountains than in deep valleys? Have the explosions of meteors been heard at great heights? How is the intensity of sounds affected in diving-bells as they are made to descend beneath the surface? 297. What three peculiarities in sound does the ear readily distinguish? Upon what does *intensity* depend? How are differences of *pitch* designated in music? If two sounds are alike in pitch and loudness, in what other respect may they differ? How is this illustrated? Can we distinguish different instruments when playing the same tune?

298. The intensity of sound, like that of attraction (§ 34) diminishes as the square of the distance from the sounding body increases. The distance at which a sound may be heard depends very much upon circumstances, as the state of the weather, the direction and force of the wind, nature of the surface over which the sound passes, &c. The noise of the cannon at the battle of Bunker Hill was heard at Pittsfield (Mass.) 120 miles distant, over the uneven surface of the land; but over the level surface of the sea the firing of guns has been heard at the distance of 200 miles. In one instance two persons held a conversation together over a frozen harbour a mile and a quarter wide. So it is observed that sounds are heard along a smooth wall much farther than in open space. On the same principle, tubes, by confining sound and preventing it from spreading, may be made to conduct it a great distance. In large manufactories speaking-tubes are often used, which, extending from the overseer's room to distant parts of the building, enable him to give his directions with precision, and without delay.

299. Pitch depends upon the number of vibrations made by the sounding body in a given time. The lowest sound that can be heard is produced by about 32 vibrations a second, and the highest by not more than 10 or 12 thousand; though it is found that ears differ, some being capable of hearing sounds so sharp as to be entirely inaudible to others. If the number of vibrations is less than about 32 per second, the ear distinguishes them separately, and a succession of blows is heard, the idea of a continuous sound not being produced. This is shown by making the end of a spring play against a toothed wheel. When the wheel is turned slowly, the successive blows of the spring are heard, and may even be counted; but if the velocity is sufficiently increased, the blows are made to succeed each other so rapidly that the ear is incapable of separating them, and a continuous sound is produced. As the wheel is made to turn more and more rapidly, the pitch becomes sharper and sharper, until the ear is incapable of judging concerning it.

300. Sound moves from place to place through the air with a velocity of about 1125 feet per second, or $12\frac{3}{4}$ miles a minute, and 765 miles an hour. It is found, however, that this velocity is somewhat affected by the temperature, state of the weather, winds, &c. By knowing the time that elapses after the produc-

Quest. 298. How does the intensity of sounds diminish with the distance? How far may sounds be heard? Why may sounds be heard further along a smooth wall or over a smooth surface than in other situations? For what purpose are speaking-tubes used? 299. Upon what does pitch depend? How many vibrations are required in a second to produce the lowest sound audible to the ear? How many to produce the highest sound? How is this illustrated by the toothed wheel and spring? 300. With what velocity does sound move? Is this velocity varied by circumstances? How may we de-

tion of a sound, we may therefore readily determine the distance of its origin with some degree of accuracy. Thus, suppose that after seeing the flash of a cannon fired at a distance, 30 seconds elapse before the report is heard; as the sound must have advanced 1125 feet every second, the whole distance to the place where the cannon was fired must be 30 times 1125, or 33,750 feet, equal to about $6\frac{1}{3}$ miles.

Suppose, again, that in a thunder-storm, a flash of lightning is seen 10 seconds before the thunder is heard; at what distance did the explosion take place? Evidently it must have been 10 times 1125, or 11,250 feet, or about $2\frac{1}{8}$ miles.

301. Sound is conveyed in liquids and solids with greater velocity than in air. In water, sound moves with a velocity of about 4708 feet per second, being more than 4 times its velocity in the air. A bell struck under water in the lake of Geneva was heard at the distance of 9 miles, the sound having been conveyed by the water.

Solids conduct sound with still greater velocity than liquids. It has been determined by experiment that cast-iron will convey sound about 11,090 feet per second, or about 10 times its velocity in air; while in some other metals, and some kinds of wood, it travels with still greater speed.

Some very easy experiments serve to show the power of solids to conduct sound. If a person places his watch on one end of a long stick of timber, and going to the other end, presses his ear against it, he will hear its ticking almost as distinctly as if his ear were directly against the watch. If his watch is placed on a table, and he touches it with one end of a long slender pole, bringing the other end to his ear, the ticking will be distinctly heard. If any part of a continuous brick wall be struck with a hammer, the sound will usually be heard by a person placing his ear against it in any other part of the building, however distant. The experiment is best performed on walls dividing the interior of buildings in which there are but few openings for doors or windows.

302. Sounds pass with difficulty from one medium to another, as from air to a solid and from the solid to the air again. Hence, a voice in a room, if not very loud, is heard but indistinctly in another separated from it by a continuous wall; since, being made in the air, it has to be transmitted to the solid constituting the partition, and then again to the air. If a light blow is struck on the dividing wall in one room, it is distinctly heard by a person standing against the wall in the

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termine the distance at which a cannon is fired, or the distance of a thunder-cloud? 301. Do liquids and solids convey sounds more rapidly than air? What is the velocity with which sound passes in cast-iron? What experiments are given to prove that solids convey sound? 302. What is said of the passage of sound from one medium to another?

other, because it is conducted directly through by the solid material of the wall.

303. Sound is readily reflected from smooth surfaces, making the angles of incidence and reflection equal, like the elastic ball when striking obliquely against a smooth surface. This constitutes what is called an *echo*. A wall, the side of a house, the surface of a rock, the ceiling and walls of an apartment, give rise to echoes which are more or less audible. When there are several surfaces at different distances from the place where the sound is produced, the echo will often be repeated from each surface in succession. At a place in Oxfordshire, England, a single syllable is thus repeated no less than 17 times. In such a place, a single *ha*, distinctly pronounced, is returned in a *ha ha ha*—a hearty laugh!

In a cathedral in Sicily, the slightest whisper behind the high altar may be heard at the opposite extremity of the building, a distance of 250 feet..

When the echoing surface is concave towards the person listening, the sound reflected from it will converge to a point, and will often be greatly increased in intensity. This is often observed in churches and public halls with vaulted roofs, in which there is usually a certain place, depending upon the position of the speaker, where he can be heard more distinctly than in any other part. In a church with which the writer is acquainted in the state of Maine, having the pulpit at one extremity, there is no better place to hear the sermon than at the foot of the gallery stairs at the other extremity, entirely out of sight both of the preacher and his audience. As the church is not large, the preacher is heard without difficulty in all parts of it; but the peculiar distinctness with which every word is heard at the point alluded to, is no doubt occasioned by the reflection of the sound from the ceiling or roof above.

In case either of the walls or roof of a church or hall designed for public speaking is made concave, as has sometimes been recommended, there must always be some favoured part where the speaker will be heard better than in other parts; hence, when it is designed that all the audience shall fare alike in this respect, the best form that can be given to them is to have them perfectly plain.

304. The rolling sound of thunder, and its sudden bursts and variations of intensity, are occasioned, it is supposed,

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Quest. 303. May sounds be reflected? What is an echo? What objects will yield an echo? When there are several echoing surfaces at different distances, what is the effect? At what distance is it said a whisper will be echoed, so as to be audible, in a certain cathedral in Sicily? What is the effect when the echoing surface is concave? What will be the effect of making the roof or walls concave of a large room designed for public speaking? What is the best form for the walls and roof of a room designed for this purpose? 304. How is it supposed the rolling sound of thunder is pro-

chiefly by numerous echoes from separate masses of clouds floating in the air at different distances, which will of course arrive at the ear successively. It may be also that the electric spark darting through the air produces the sound, not in a single point, but all along its zigzag course, at different distances from the ear. The original report, therefore, though perfectly instantaneous, yet being produced at different distances from the ear, will arrive from different points in successive parts, and will thus become prolonged.

The production of echoes often depends upon the state of the atmosphere as it regards barometric pressure, temperature, moisture, the direction and force of the wind, &c. Thus, we can occasionally hear a very distinct echo from a distant building, or other object, from which an audible return-sound cannot usually be obtained.

305. When a distinct echo can be obtained from a distant object, it may be made use of to determine its distance. Thus, suppose that from a building on the opposite bank of a river, an echo is returned to an observer in 4 seconds, it is required to determine the width of the river. As the sound must go and return, it is evident the distance must be equal to that over which sound would pass in half the time, or 2 seconds. Its width is, therefore, $1125 \times 2 = 2250$ feet, or 750 yards.

306. Sounds in the open air are partially intercepted by opposing obstacles, forming what has been called an *acoustic shadow*. Thus, a band of music, in passing through the streets, is heard much less distinctly after going behind a block of buildings, than before any object intervened. In water, sounds are almost entirely cut off by intervening objects.

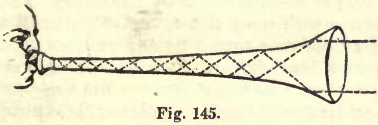

Fig. 145.

307. We have seen above (§ 298), that tubes may be made to convey sound distinctly a considerable distance, which no doubt is to be attributed to the reflection of the sonorous waves from side to side in their passage. It is on this principle too that the *speaking-trumpet* acts, by which a person is enabled to hold a conversation with another at a much greater distance than he otherwise could. It is made in the form of a hollow cone, having a portion removed at the apex to which the mouth is applied, the instru-

duced? May the sound also be produced along a line for some distance, so as to be at different distances from the ear? Will the production of an echo from an object often depend upon the state of the atmosphere? 305. How may we by means of the echo from a distant object determine its distance? 306. Is the passage of sound in the open air interrupted by intervening objects? How is this shown by a band of music marching through the streets? 307. To what is the conveyance of sound in tubes to be attributed? On what principle does the *speaking-trumpet* act? What is its form? What is the design of the *ear-trumpet*?

ment being directed towards the person addressed. It is represented in figure 145.

The *ear-trumpet* is designed to assist the hearing of persons who are partially deaf, by collecting the vibrations and conducting them to the ear. It is made of the same form as the speaking-trumpet, and is used by applying the small extremity to the ear.

308. *Music.* — Music is the art of producing and combining sounds in a manner agreeable to the ear. A musical sound is produced when the impulses or vibrations occur at exactly equal intervals, and are of similar intensity and quality. Such a sound always produces a pleasing effect upon the mind; but if too long continued, it becomes tedious and requires to be changed.

309. Though intensity and quality are by no means to be neglected in music, yet the most important circumstance to be attended to is pitch. This we have seen (§ 299) depends entirely upon the frequency of the vibrations, or the number which occur in a given time; and two sounds in which these elementary impulses occur with the same frequency are said to be *in unison* or to have the *same pitch*, whatever may be their intensity or quality.


Fig. 146.

310. A stretched cord or wire furnishes an excellent instrument for the investigation of many points connected with this subject. When such a cord or wire is drawn a little out of its position of rest, and suddenly let go, it will continue for a time to vibrate backward and forward over its position of rest, as represented in figure 146, producing a sound gradually diminishing in intensity, but continuing of the same pitch until it ceases. The vibrations of a cord are much better excited by a *bow*, which, as is well known, consists of a bundle of horse-hairs loosely stretched by means of an instrument for the purpose, and rubbed with rosin to make them adhesive. The pitch of such a cord or wire is found to depend upon three circumstances, viz: its length, size or weight, and the force with which it is stretched. By an increase of the length or of the weight, the pitch is made to fall, or become more grave; but by increasing the tension, it becomes more acute or sharp.

Hence, the same cord may be made to give sounds of different

Quest. 308. What is music? How is a musical sound produced? Are the *intensity* and *quality* of musical sounds important? 309. What is the most important circumstance requiring attention? Upon what does the pitch depend? When are two sounds said to be in unison? 310. How is a stretched cord made to vibrate so as to produce a sound? For what purpose is the bow used with a stringed instrument, as the violin? Upon what will the pitch of such a cord depend? By what change may the same cord be made to give sounds of different pitch? How is this accomplished in the violin and violoncello?

pitch by simply changing its length. This is done in stringed instruments like the violin and violoncello, by pressing the string upon a support placed just below it, while the bow is drawn over it. In the piano forte, each wire gives but a single sound to which it is adjusted, depending upon the three circumstances above named.

311. Sometimes a string does not vibrate as a whole, but divides itself spontaneously into parts, each of which vibrates separately, producing its own note, which is the same as if the string was only of that length. The points of division between the parts vibrating in such a case, are called *nodes*, or *nodal points*.

312. In wind instruments, as the organ, flute, &c., the vibrations are produced in the column of air within the instrument, and depend upon its length, and in some respects also upon the size. In the organ, the different sounds are produced by different pipes, each of which is so adjusted as to produce a single sound of the proper pitch; but in the flute, clarinet, &c., different lengths are given to the vibrating column by the fingers and keys opening and stopping the apertures, as may be required. The note produced by one of these instruments will also depend to some extent upon the manner of blowing it.

Wind instruments are of two kinds, those with reeds, and those without them. Of the former kind are the clarinet and bassoon; of the latter, the flute, serpent, bugle, &c. In the accordion, the sound is produced entirely by reeds, which are slender strips of metal made to vibrate in a small aperture, through which the air passes.

313. Music may be considered as composed of two parts, *melody* and *harmony*. Melody depends upon the order or succession of the sounds, and the time during which they are severally continued. A musical sound, however pleasing at first, soon becomes disagreeable if continued, and must therefore be succeeded by another, and this by a third, and so on. Now the peculiar order in which the several sounds succeed each other in a piece of music, constitutes its melody. Harmony, on the other hand, depends upon the union or blending of two or more different sounds, which must sustain certain relations of pitch to each other. When two sounds heard together produce an agreeable effect upon the ear, they are said to *chord*, or to form a *chord;* when they do not harmonize so as

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Quest. 311. May a string sometimes vibrate in parts? What are the *nodes* or *nodal points?* 312. In wind instruments, what is to be considered the vibrating body? Upon what will the pitch depend? How are the different sounds produced in the organ? How in the flute, clarinet, &c.? Will the manner of blowing the flute also affect the note it will give? 313. What two parts may music be considered as composed of? Upon what does melody depend? Will a musical sound that is at first pleasing become disagreeable if long continued? Upon what does harmony depend? When are two sounds said to *chord?* When are two sounds said to produce a *discord?*

to produce this agreeable effect, they are said to be discordant, or to produce a discord.

314. The first and best chord is called a *unison*. It is produced by two sounds having the same pitch; that is, two sounds whose vibrations are performed in the same time. The next chord or concord is the *octave*, in which the vibrations are as 1 to 2. As third in point of agreeableness, we may mention the *twelfth* from the fundamental note, in which the vibrations are as 1 to 3; and next, the *fifth*, in which the vibrations are as 2 to 3.

315. If we begin with any particular sound, and then ascend by seven regular steps, we produce the *diatonic* or *natural scale;* which is a series of notes, that, with little variation, has been adopted by all nations, in all ages of the world, as the foundation of their music. This scale is sometimes called the *gamut*. The last or eighth note is always the octave of the first, called the fundamental note, and seems to the ear to be merely a repetition of it. If we ascend above this, or descend below it seven more notes, we only repeat the same series, the latter notes being the several octaves of the former.

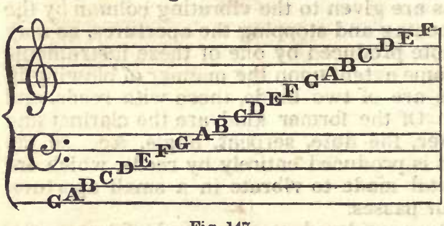

Fig. 147.

316. Music is written on several horizontal lines and the intermediate spaces, as represented in fig. 147; and the several notes of the natural scale are represented by the first seven letters of the alphabet, which are placed as in the figure. These notes are also represented by the seven syllables *do*, *re*, *mi*, *fa*, *sol*, *la*, *si*, the first syllable here used being always applied to the fundamental note, called the *tonic*, which in the natural key is always on the line or space denoted by the letter C.

These several notes are supposed to differ from each other only in pitch, which, as we have seen, depends entirely upon the number of vibrations in a given time. In producing these sounds, however, nothing depends upon the absolute number of vibrations, but only their ratio to each other. Whatever may be the number of vibrations in the fundamental note, in the second, or next above it, there must be 9 in the same time

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Quest. 314. What is the most agreeable chord? How is it produced? What is the next best chord? What the third? 315. What is meant by the *diatonic* or *natural scale?* What is the eighth note considered? 316. How is music written? For what are the first seven letters of the alphabet used? What syllables are used for the same purpose? In producing the sounds of the diatonic scale, is the absolute number of vibrations in a given time to be noticed, or only their ratio to each other? Whatever may be the number of vibrations in a given time in the fundamental note, how many must be made in the same time to produce the second, or next above it? To

in which there are 8 in the first. In the third there must be 5, while there are 4 in the first; in the fourth, 4, while there are 3 in the first, &c., as will be seen by the following table.

In the following table, the numerator of each fraction in the second horizontal line indicates the number of vibrations made in sounding the letter under which it is placed, in the same time that in sounding the fundamental note, C, the number of vibrations is made which is expressed by the denominator. Thus, in sounding D, 9 vibrations are made in the same time that 8 are made in sounding C; in sounding A, 5 vibrations are made in the same time that 3 are made in sounding C, &c.

In the lower line are the syllables generally used in singing these several sounds.

Letters.	C	D	E	F	G	A	B	C
Ratio of vibrations	1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2
Syllables	*Do*	*re*	*mi*	*fa*	*sol*	*la*	*si*	*do.*

317. The space between two notes is called an *interval;* that from any note to the next, as from the first to the second, or from the second to the third, is called the interval of the second; that from the first to the third is called the interval of the third, and so on. The five intervals from C to D, from D to E, from F to G, from G to A, and from A to B, are very nearly equal, and are called *tones;* while the two from E to F, and from B to C, are much less than the former, and are therefore called *semi-tones.* The whole octave, therefore, contains five tones and two semi-tones. The expert arithmetician will perceive more clearly the relations of the tones and semi-tones by reducing to a common denominator the fractions in the second horizontal line in the table, and then comparing them together.

318. When all these notes are sounded in succession, in either the ascending or descending order, the effect is always pleasing; but the great variety of melody in music is produced by causing these and other intervals to succeed each other in every possible order and mode of transposition.

319. As has before been stated (§ 313), when two notes of the scale are sounded together, a pleasing effect is produced upon the ear, and it is called a *chord;* or a displeasing effect, and it is then called a *discord.* But of the chords, some are

produce the third, how many must there be, while there are 4 in the first? What is shown by the upper and lower figures in the second horizontal line in the table? 317. What is an *interval?* What is the interval of the second? What the third, fourth, &c.? What are *tones?* What are *semi-tones?* How many tones and semi-tones constitute the octave? 318. What is the effect when the notes of this scale are sounded in succession? How is the great variety produced in music? 319. What is the difference in the

more and some less pleasing; and so of the discords, some are much more offensive than others. When two notes immediately together, as C and D, or D and E, are sounded at the same time, a discord is always produced, which is called the discord of the second; so also C and B, sounded together, produce a discord, called the discord of the seventh.

On the other hand, C and E, sounded together, produce a very agreeable chord, as do also C and G. Numerous other chords and discords may be found by searching for other combinations, but we cannot here introduce them.

320. But what occasions the difference between the chords and discords? Why are the former agreeable and the latter disagreeable?

The difference without question is to be attributed to the comparative rapidity of the vibrations in the two notes which are sounded together. When the vibrations are to each other in the simple ratios of 1 to 2, 1 to 3, 1 to 4, 2 to 3, &c., it is invariably found that chords are produced, which are more agreeable to the ear as the terms of the proportion are lower.

On the other hand, discordant notes are those in which the vibrations bear no simple ratio to each other. Thus, in the discord of the second, the vibrations are as 8 to 9, and in the discord of the seventh, as 8 to 15.

This subject may be illustrated by using waved lines to represent the different sounds, as in figures 148, 149, and 150. When the interval between two sounds is just an octave, the number of vibrations in the lower are to those in the higher sound, as 1 to 2 (§ 314); so that every second wave or vibration of the latter sound will coincide with each wave of the former.

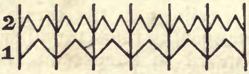

Fig. 148.

This is the most simple ratio we can have, and, as we have seen, produces the most agreeable chord. The sounds are illustrated by the waved lines in figure 148. The perpendicular lines show the waves which coincide.

When the interval between two sounds is what is called a fifth, a very pleasing chord is produced; and the number of vibrations in each in a given time are as 2 to 3, as represented in figure 149. The perpendicular lines indicate, as be-

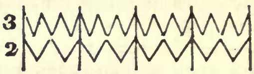

Fig. 149.

effect upon the ear between a chord and a discord? Are all the chords equally pleasing? Are all the discords equally disagreeable? What is meant by the discord of the second or of the seventh? 320. To what is the difference between chords and discords to be attributed? When are chords produced? When are the notes discordant? How may this subject be illustrated? When two sounds differ from each other by an octave, what vibrations of each will coincide? When they differ by a fifth, what vibra-

fore, the coinciding waves; every third one of the sharper sound, it will be seen, coincides with every other one in the lower.

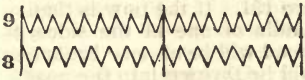

Fig. 150.

Figure 150 is designed to indicate what is supposed to take place in the discord called the discord of the second (§ 319), in which the vibrations are as 8 to 9. The coinciding waves, it will be observed, are much farther from each other than in the case of the chords represented above, every 9th of the upper coinciding with the 8th of the lower. Indeed, it is found in the case of chords, that, as the coinciding waves are removed farther and farther from each other, they become less and less pleasing, and at length, when removed to a certain distance, decidedly discordant.

321. In our description of the diatonic scale (§ 315), C is taken as the fundamental note, and the position of the several tones and semi-tones with reference to it described. This is called the natural *key*. Any other letter may, however, be taken for the fundamental note, but the several tones and semi-tones must always have their proper position in relation to it. To accomplish this, other keys are formed by means of flats and sharps, for a description of which the intelligent student is referred to works that treat at large on this subject.

322. *Vibrations of Bodies.* — There are many important points connected with the vibrations of bodies, which have not yet been noticed. Planes, as well as chords and bells, may be made to vibrate so as to produce distinct musical notes. A plate of glass or of metal answers well for this purpose, and is to be used by holding it firmly in a wire prepared for the purpose, and drawing the bow against the edge. It is found that the note produced will depend upon the manner in which it is held in the wire, and the part against which the bow is drawn, the mode of using the bow, &c.

When a plate of glass or metal is thus made to vibrate, the vibrations are always performed in segments which are separated by *nodal* lines. If the plate be in a horizontal position, and fine sand scattered upon it, the sand will leave the parts in which the motion is greatest, and collect on the nodal lines.

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tions coincide? What is illustrated by figure 150? What vibrations coincide in this case? 321. On what letter is the fundamental note or tonic in the natural key? How are other keys formed? 322. May planes be made to vibrate so as to produce musical sounds? How may a plate of glass be used for this purpose? Will the plate always vibrate in segments? How may the *nodal lines* be shown? Will these lines always occupy the same position? What is illustrated by figures 151 and 152?

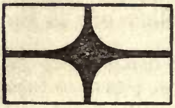

Fig 151.

If the plate is of a rectangular form and held by the centre, when the bow is drawn near one of the corners, the sand will arrange itself as in figure 151. If the bow is then applied to the middle of one of the sides, the figures first formed will be at once broken up, and the sand will be thrown into the position represented in figure 152. In some instances differences in the arrangement of the sand will be produced by different modes of using the bow as just intimated; and for every arrangement of the sand a distinct tone is always produced. If, for instance, a circular plate is used, held by the centre, and the bow rubbed against it very lightly, the circumference will be divided into four parts, and a low note will be produced, the sand arranging itself as in A, figure 153. If the bow is then pressed a little harder against the edge, the sound will become sharper, the figures first formed by the sand will be broken up, and a new arrangement take place as in B, in which the circumference is divided into six parts or segments. By proper means the same plate may be made to give still higher sounds, the sand each time forming a distinct arrangement, and showing that the circumference is divided by the vibrations into a still greater number of parts, as 8 or 12.

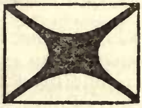

Fig. 152.

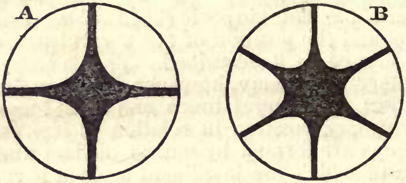

Fig. 153.

323. The parts of a glass vessel, as a tumbler, may be easily made to vibrate and give a musical sound by drawing a violin-bow across the edge, or by wetting the finger and rubbing it on the edge. If the vessel is partly filled with water, the vibrations of the glass will give a peculiar tremulous motion to the surface. If the vessel be large, it may be made to vibrate so rapidly as to throw it to pieces.

324. Vibrations in one body may be communicated from it to another through intermediate solid bodies, or even through the air. The heads of a small drum will always be seen to vibrate when a larger one near it is struck, even though they do not touch each other. The vibrations are communicated through the air. So when the note D is sounded on the largest string of the violoncello, the D string above, if in tune, will be

Quest. 323. How may a tumbler or other glass vessel be made to vibrate so as to produce a musical sound? Will there be any danger of breaking the vessel in performing the experiment? 324. May the vibrations of one body be communicated to another? What purpose does the body of a violin

observed to vibrate rapidly, the vibrations being transmitted either through the air, or through the solid parts of the instrument.

The jarring of the earth by heavy thunder is no doubt to be explained on the same principle; the immense vibrations are communicated even to the solid earth.

The body of the violin, violoncello, guitar, &c., is designed, by vibrating in unison with the sounds of the strings, to increase the intensity. Without this assistance the sounds would be scarcely audible at the distance even of a few feet. A music box placed on a table, while playing sounds much louder than when held in the hand for the same reason.

Formerly, "sounding-boards" were placed over the pulpits in churches, with the design of assisting the voice of the speaker, but the practice is now discontinued as useless.

325. *The Ear.* — The parts of the ear are very different in different species of animals; but in all, and especially in man, they are exceedingly complex and difficult to be fully understood.

The external ear in some animals, as the ox and the horse, is evidently designed to collect the vibrations, like the ear-trumpet (§ 307), used by the deaf, and convey them to the organs of hearing within, thus increasing the intensity of the sound. These animals, therefore, have the power of turning their ears in different directions from which the sound may proceed. The horse, if suddenly startled, will always be observed to turn his ears intently towards the supposed point of danger.

But the human ear is not fitted so well to reflect the vibrations of the air directly into the passage leading to the internal ear, as it is to receive and transmit them there through the solid parts of the head. But it is supposed to be of little use as connected with the sensation of hearing, which is found to be little affected by its loss.

326. The several parts of the internal ear in man are the conical-shaped passage leading from the external ear, about nine-tenths of an inch in length, the tympanum or ear-drum, with four very small bones connected with it, the Eustachian tube, and the labyrinth.

The tympanum is a thin membrane drawn like the head of a drum quite across the passage leading from the external ear, and is designed to receive the vibrations from the air with which the passage is filled. The four small bones connected

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or violoncello serve? Why are the sounds of a music box more distinctly heard when it is placed on a table than when held in the hand? 325. Are the parts of the ear different in different animals? What is the design of the external ear in many animals? Is the human ear fitted for this purpose? 326. What are the several parts of the internal ear in man? What is the tympanum? What is its design? What purpose do the four small bones

with the tympanum are so arranged as to transmit its vibrations, somewhat increased in intensity, to the labyrinth, which is composed of a number of bags or sacks, and semicircular canals, all of which are filled with fluid. In this fluid are the terminations of the auditory nerves, which lead directly to the brain.

The Eustachian tube is a passage leading from the upper part of the mouth to a small cavity behind the tympanum, called the cavity of the tympanum. This passage prevents any unequal pressure of the air upon the tympanum, from variations of the atmospheric pressure, or from any other cause. Sometimes the parts about this passage become inflamed so as to close it, which always produces a sensation like that of a constant roaring sound. This sensation almost every one has experienced on taking a severe cold.

The stunning effect often produced by the firing of a cannon near a person, is occasioned by the sudden and violent concussion of the air against the tympanum, and through that upon the air within the cavity of the tympanum. It is said it may always be avoided by having the mouth open at the time of the explosion; the air is then allowed to pass freely through the Eustachian tube.

The firing of cannon near windows will often break the glass by the violent vibrations of the air against it; but such an effect may be prevented usually by opening one or more of the windows in each apartment, so as to form a free communication between the air within and that without.

327. *The Voice.*— The organs of the voice consist of the parts called the *thorax*, the *trachea* or *windpipe*, the *larynx*, the *mouth*, *nose*, and other adjacent parts.

The air during respiration, as we have seen (§ 247), is constantly passing inward and outward through the trachea, by the alternate expansion and contraction of the cavity of the chest. Voice is always produced as the air passes outward, chiefly by its action on the larynx, which may be considered as the musical organ of the voice. It is a short tube with several important appendages, situated at the head of the windpipe, and is the organ of the voice upon which its pitch almost entirely depends. But in producing the innumerable, nameless modifications of sound, of which the voice is capable, and which are required in ordinary speech, other organs are concerned, as the tongue, palate, lips, teeth, nose, &c., though the distinct office of each cannot be fully determined.

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connected with it serve? What is the Eustachian tube? Of what use is it? How may the stunning often experienced when standing near a cannon that is fired be avoided? How may the breaking of windows by the firing of cannon in the vicinity be to some extent avoided? 327. What are the organs of the voice? How are the sounds of the voice produced? What organ does the pitch of the voice chiefly depend upon? What other organs are brought into use in producing the great variety of sounds of which the voice is capable?

328. *Ventriloquism* consists in imitating very accurately those peculiarities of sounds, by which we judge of their distance and position, with reference to ourselves. Thus, when a person hears a sound, he is usually able to determine at once whether it was produced in the same apartment with himself, or in an adjoining apartment, by certain peculiarities it possesses, which he has learned from experience. Now, Mr. A. is in the same room with Mr. B., but is able to give his voice the peculiarities it would have if coming from a room adjoining; Mr. B., not knowing the deception, will imagine he hears a person in that room. In the same manner, sounds may be made to appear to come from any other place, as from the open air, from the earth, from the body of a person, &c., by imitating the peculiarities which our experience tells us might be expected in sounds coming from those places. Usually the ventriloquist will direct the attention of his audience to the point from which the sound is expected, which very much assists in the illusion.

CHAPTER V.

OPTICS.

329. Optics is that branch of science which treats of the various phenomena of light and vision.

It is by means of light that we see objects; but it has not yet been found possible to determine certainly what this agent really is. Two important theories concerning it have been proposed, each of which at different times has been very generally adopted.

The first of these theories is that of the illustrious Newton. It supposes all the phenomena of light and vision are produced by exceedingly small particles which are thrown off by luminous bodies, and which move through space and all transparent bodies with immense velocity. The particles are supposed to

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Quest 328. In what does *ventriloquism* consist? When we hear a sound, how do we know whether it originates in our own apartment or an adjoining one? If two men, A and B, are in the same room, how may A produce a sound that to B will appear to come from an adjoining room? How may he cause his voice to appear as if coming from any other place? Why do ventriloquists usually direct the attention of the audience to the point from which the sound is expected to come? 329. What is treated of in optics? Can we determine with certainty whether light is really material? What important theories have been proposed concerning it? What is Newton's theory?

be constantly emanating from all self-luminous bodies, and flying off in every direction, and capable when coming in contact with other matter, of being reflected, refracted, absorbed, or transmitted.

330. The other theory, proposed by Huygens, is usually called the *undulatory theory.* It supposes there is everywhere diffused in space, even in the most solid transparent bodies, filling up the interstices between their particles, an exceedingly subtile and elastic fluid, in which undulations or oscillations are excited by luminous bodies, and transmitted with immense velocity, producing the phenomena of light, much in the same manner as vibrations in the air (§ 295) produce the phenomena of sound. The movements thus excited in this subtile medium or ether, are readily propagated through a vacuum (which is indeed filled with the ethereal medium), and through the most solid transparent bodies; but in this last case, the elasticity of the medium being somewhat diminished, the movement is less rapid than in free space.

331. These undulations, or oscillations, however, are in some respects unlike the waves produced upon the surface of smooth water, when a pebble is thrown into it, being rather oscillations in the particles themselves, which are supposed to be propagated from particle to particle in much the same manner as was explained in the use of the ivory balls (§ 104).

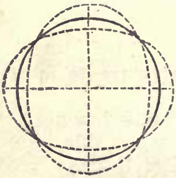

Fig. 154.

Assuming that the particles are spherical, we may suppose that each one of them becomes alternately extended and depressed, horizontally and vertically, as represented in figure 154; or, more properly, at its poles and equator. Thus, the motion is an oscillatory tremulous motion, and may be propagated to distant particles without the intermediate ones being moved out of their places.

332. The waves of light, like those of sound, are transmitted in every direction, extending on every side of the luminous body, the intensity diminishing as the square of the distance increases. The sonorous vibrations of a sounding body, as a bell, it will be recollected, are conveyed to the ear, through the atmosphere, by means of the particles of the latter assuming a similar wave-like movement; and, in the same manner, a luminous body, as the sun, or a lamp, it is supposed, by exciting

Quest. 330. What is the theory of Huygens called? How are the phenomena of light supposed to be produced on this theory? Does the supposed subtile medium, called ether, pervade even solid bodies? 331. Are the waves or oscillations of this medium like waves upon the surface of water? How may we suppose the particles of ether alternately extended and depressed? May these oscillations be propagated through the ether without its particles being moved out of their places? 332. Are the waves propa-

an analogous oscillatory movement in the universal ethereal fluid, which is propagated from particle to particle until it reaches the eye, communicates to this organ the sensation of vision, just as the sonorous vibrations produce in the ear the sensation of sound. Darkness, therefore, is occasioned by the cessation of this oscillatory movement, or the repose of this supposed fluid, called ether, just as silence results from the cessation of the similar movements in the air.

It is impossible in the present state of science to say which of these theories—or whether either of them—is true; but the undulatory theory is now almost universally adopted by scientific men, as it accords much best with well-settled facts. But, in discussing the principles of the science, we shall, notwithstanding, continue to speak of light as a material substance transmitted from place to place, and capable of being thrown out of its course, and otherwise variously acted on by other substances—language which would seem to belong to the other theory, the theory of emission.

333. All visible bodies may be divided into the two classes of *luminous* and *non-luminous*. The former are those which shine by their own light, as the sun, the stars, flame, &c.; the latter those which have not the power of discharging it themselves, but are capable of throwing back the light, or part of the light, they receive from self-luminous bodies, by which they are seen, or become visible. In every case the light must come from a self-luminous body, though it may have been several times reflected before meeting the eye. When a lighted candle is brought into a dark room, the form of the flame is seen by the light which proceeds directly from the flame itself; but the objects in the room are seen by the light which they receive from the candle, and again thrown back to the eye. Other objects still there may be in the room, which are so situated as not to receive any light directly from the candle, but become visible by the light reflected from the wall and ceiling, &c. of the room.

Light is emitted from every visible point of a luminous or an illuminated body, and in every direction.

334. *Transparent* bodies are such as transmit light freely, so that objects may be seen through them. Bodies that transmit the light, but not sufficiently to render objects visible through them, are said to be *translucent*. Substances that do not permit light to pass through them in any degree are called *opake*. But this term is sometimes used to mean the same as non-luminous.

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gated in every direction? What is darkness? Is the undulatory theory of light now generally adopted? 333. Into what two classes may all visible bodies be divided? What are *luminous* bodies? How are non-luminous bodies seen, as no light is emitted by them? Must the light always originate from a luminous body? Is light emitted from every point of a luminous body? 334. What are *transparent* bodies? When are bodies said to be *translucent*? When are they said to be opake?

335. A *ray* is merely a small portion of light; the smallest portion that can be intercepted or examined. A large ray, or a combination of rays, is sometimes called a *pencil* or *beam of light.*

336. The rays of light may be *parallel*, or they may be *convergent*, or *divergent*. Parallel rays, as the term implies, are everywhere equally distant from each other; but convergent rays approach each other as they advance, while divergent rays separate.

The surface of a body may be considered as made up of a great multitude of very small points, and from every one of these in a luminous body the rays of light are thrown off; consequently, the rays from a luminous body near us must always be divergent; that is, they must always separate farther and farther as they advance.

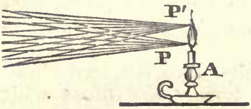

Fig. 155.

Thus, let A, figure 155, represent a lighted candle, and P and P′ two pencils of rays emanating from points in it; it will be seen that as they advance they diverge or separate more and more from each other. In this case we have represented the rays thrown off from two points only — and indeed only a part of those from each of these points, since many more rays both above and below those shown in the figure, proceed from the same points. To obtain a correct idea of what really takes place, it is necessary to recollect that pencils of rays are proceeding in this manner from every point of the flame of the candle, crossing each other in every direction.

As a necessary result of this divergence of the rays of light, it must at length become so expanded as to cease to affect the eye; and the body from which it emanates will then be invisible.

Rays of light from a luminous body can, strictly speaking, never be parallel; but, when their source is exceedingly distant, as in the case of rays from the sun or any other celestial body, it is evident they may be considered so.

The direct rays of a luminous body can never converge; in order to be convergent, they must first be reflected or refracted, as will be seen hereafter.

337. The passage of light is progressive, it requiring about $16\frac{2}{3}$ minutes to cross the earth's orbit, or about $8\frac{1}{3}$ minutes to come from the sun to the earth. This is best determined by

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Quest. 335. What is a *ray* of light? What is a *pencil* or *beam?* 336. When are rays said to be *parallel? Convergent? Divergent?* What may the surface of a body be supposed to be made up of? Is light emitted from each point? Will the rays from a body near us always be divergent? How is this shown in figure 155? May rays from a very distant body be considered parallel? Can the direct rays from a luminous body ever converge? 337. Is the passage of light progressive? How long is light in coming from the sun? By what means is this determined? What is the velocity of light

means of the eclipses of Jupiter's satellites, which are constantly taking place.

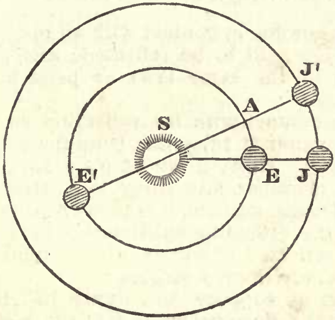

Fig. 156.

The earth and Jupiter, in their revolutions round the sun, are sometimes both on the same side of that luminary, and at others they are on opposite sides. In figure 156, let S be the sun, E the earth, and J Jupiter; both the earth and Jupiter being now on the same side of the sun. The light from Jupiter, in coming to the earth, will now have to pass through the distance J E only. But, in a little more than six months after the earth and Jupiter are in the position above supposed, the earth will have advanced to E′, and Jupiter to J′; they will then be on opposite sides of the sun; and the light from Jupiter, to reach the earth, will have to traverse the whole distance J′ E′, which is greater than J E by the distance A E′, or the diameter of the earth's orbit.

Now, when these two bodies are in the position last indicated, in reference to the sun, the eclipses of Jupiter's moons are uniformly found to take place about 16⅗ minutes later than when they are in the first position; that is, when they are on the same side of the sun. This shows that light is this period of time in passing from A to E′; or, about 8⅓ minutes in passing from S to E′, or from the sun to the earth.

The velocity of light is therefore about 192,000 miles a second, which is evidently so great that we are absolutely incapable of measuring the time that is required for light to pass any distance over the earth's surface. Indeed, in one second it would pass no less than 8 times quite around the earth.

The progressive motion and the velocity of light are also shown by the phenomena of aberration, which, however, cannot be here explained.

338. In the same medium, light always moves in a straight line; it is, therefore, impossible to see through a bent tube.

339. When light falls upon an opake object, it is intercepted, and darkness, more or less intense, is produced on the opposite side, called a *shadow*, or *umbra*. This is always surrounded by a border less dark than the shadow itself, which is called the *penumbra*. It is occasioned by the interception of a part of the light from the luminous body. An eye situated in the penumbra will always be able to see a part, and only a part, of the luminous body.

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per second? How many times would light pass round the earth in a second? 338. Does light always move in a straight line in the same uniform medium? 339. What is a shadow? By what is the shadow always surrounded? How is this occasioned? Will an observer see the whole of a luminous body when his eye is in the penumbra?

REFLECTION OF LIGHT.

340. When rays of light, on coming in contact with an opake body, are thrown back, they are said to be reflected; and in its reflections it is governed by the same laws as perfectly elastic solid bodies. (§ 62).

The ray, before it comes in contact with the reflecting surface, is called the *incident* ray; after it rebounds from the surface, it is called the *reflected* ray. Now, if we admit a single ray of light into a darkened chamber, and cause it to strike perpendicularly against a reflecting surface, it is thrown or reflected directly back; but if the reflecting substance is held a little inclined to the ray, it is reflected obliquely, and a luminous spot is seen on the wall where the ray strikes.

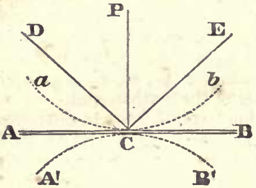

Fig. 157.

Let us suppose A B, figure 157, to be the reflecting body, E C the incident ray, and C D the reflected ray. If, now, at C, the point of contact, we erect a perpendicular, C P, then E C P will be the angle of incidence, and P C D the angle of reflection; and these two angles will always be equal.

It is not necessary that the reflecting surface should be a plane; it may be concave, as *a b*, or convex, as A′ B′, and yet the ray will obey the same law.

341. A good reflecting surface is called a *mirror* or *speculum*. Mirrors are made usually of polished metal, or of glass, covered on the back with an amalgam of tin.

342. A considerable portion of light is always lost on coming in contact with reflecting surfaces, no mirror being capable of throwing back or reflecting all the light. The more inclined the incident ray is to the reflecting surface, the greater will be the proportion reflected. Thus, it is found that when the angle of incidence is 85°, from the surface of water about 501 out of 1000 parts are reflected; but when the angle of incidence is only 20°, then only 18 out of 1000 rays are reflected. When the reflector is transparent, as a glass plate, much more light is reflected from the second than from the first surface; and this proportion is increased when the back is coated with some resinous cement or black paint; or, better still, some metallic amalgam, as in the common looking-glass. In this case the reflections become very vivid, and the images of objects bright.

343. Mirrors are made of various forms, of which the chief are *the plane*, *the concave*, and *the convex*. The common looking-glass is an instance of a plane mirror; it consists simply of

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Quest. 340. When is light said to be reflected? What is meant by the *incident*, and what by the *reflected* ray? What are the angles of incidence and reflection in figure 157? Must the reflecting surface be a plane surface? 341. What is a *mirror?* 342. Will all the light be reflected? 343. What different forms of mirrors are mentioned? What is the form of the *plane*

a plain, level, polished surface. The concave mirror is a portion of the inside surface of a hollow sphere, — usually but a small portion of the whole sphere. The convex mirror, in like manner, is a portion of the external surface of a sphere. A line perpendicular to the centre of a concave or convex mirror is called its axis.

344. Rays of light reflected from a plane mirror always retain the same direction with reference to each other after reflection as they possessed before. Thus, rays parallel before reflection will be reflected parallel; and rays convergent, or divergent before reflection, will be reflected convergent or divergent, as the case may be. This may be more clearly understood by referring to figure 158.

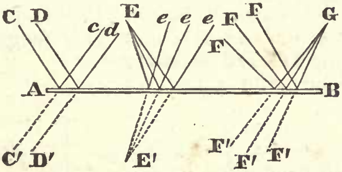

Fig. 158.

Let A B be a plane mirror, and C D two parallel rays; after reflection they take the direction *c d*, and to the eye they will appear to come in the direction C′ D′. *Diverging* rays proceeding from a point, E, will be reflected in the direction *e e e*, and will appear to come from the point E′ behind the mirror. So will the converging rays, F F F, be likewise reflected converging; and they will meet in the point G, just as if they originated in the direction F′ F′ F′. The effect of reflection in every case is to throw the *apparent* origin of the rays on the opposite side of the mirror, since objects always appear to the eye to be situated in the direction of the rays which finally reach that organ.

345. Rays reflected from a concave mirror are in general made to converge; or if they are very divergent, they are made to diverge less. Parallel rays are made to converge to a point called the principal *focus* of the *mirror*, which is about midway between the centre of the sphere of which the mirror is a part, and the surface of the mirror.

Let A E B, figure 158 *a*, be a concave mirror; C, the centre of the sphere of which the mirror forms a part; and *d e f g h* parallel rays. After reflection they will be collected in the focus, F, where the light and heat of all the rays will of course be

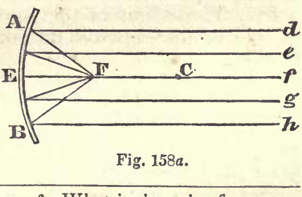

Fig. 158*a*.

mirror? The *convex* mirror? The *concave*? What is the axis of a convex or concave mirror? 344. Do rays of light reflected from a plane mirror always retain the same direction with reference to each other after reflection as before? How is this illustrated by figure 158? 345. How are rays reflected from the concave mirror? What is the *focus* of a concave mirror?

concentrated. E F is called the *focal distance*, or the *principal focal distance* of the mirror.

From what has been said it is evident that rays emanating from the focus F will be reflected parallel.

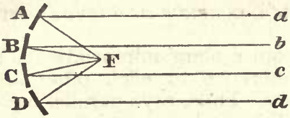

Fig. 159.

It is evident the concave mirror may be considered as a multitude of plane mirrors inclined towards each other. Let A B C D, figure 159, be four plane mirrors arranged on the circumference of a circle, and *a b c d*, several parallel rays; these rays will strike the mirrors at different angles, and obey the usual law (§ 340); but they will all be reflected very nearly to the same point, F.

Rays converging before reflection are, by reflection from the concave mirror, made more convergent; and their focus is nearer the mirror than F, the focus of parallel rays.

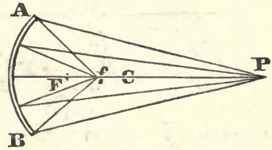

Fig. 160.

346. Diverging rays will be made less divergent, or parallel, or convergent, according to their comparative divergency before reflection. Suppose them to be radiated from a luminous body situated at P, figure 160; then, after reflection, the focus will be, not at F, as before, but at *f*, a point nearer the centre, C. If, now, the radiant point, P, be made to approach the centre C, the focus *f* will also gradually approach to C; and when the radiant, P, reaches that point, its rays, it is evident, will be reflected directly back. If P is carried still nearer the mirror A B than C, *f* will recede beyond C to the right, and the two foci will at length change places. The two points, P and *f*, are therefore sometimes called *conjugate foci*, to represent their intimate relation to each other. If, however, the luminous body be placed nearer the mirror than F, which is the focus of parallel rays, its rays will be reflected, not parallel, but divergent, as though they emanated from some point behind the mirror.

347. The effect of the *convex* mirror is directly the reverse of that of the concave mirror; it separates the rays after reflection.

Where is it situated ? What is the *focal distance* of a concave mirror ? What may the concave mirror be considered as made up of? 346. How will diverging rays be reflected by the concave mirror ? Will the focus of diverging rays be the same as if they were parallel ? If the radiant point, P, figure 160, is made to approach the mirror, how will the focus be affected ? If the luminous body is placed nearer the mirror than its principal focus, what will be the effect ? 347. What is the effect of the convex mirror upon rays of light ? From what point will the rays appear to emanate ? What is this point called ?

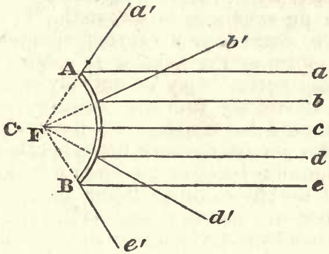

Fig. 161.

Thus, let *a b c d e*, figure 161, be several parallel rays incident upon a convex mirror, A B, of which C is the centre of convexity; they will be reflected according to the general law, making for each ray the angle of incidence equal to the angle of reflection; the ray *a* will therefore take the direction of *a′*, *b* that of *b′*, *d* that of *d′*, and *e* that of *e′*. They will all appear after reflection to come from the same point, F, behind the mirror, which is therefore called the *virtual*, or *apparent* focus. In the case of converging rays, the distance of F from the mirror will be greater, and in that of diverging rays, less, than for parallel rays.

348. When a pencil of rays falls upon a concave surface, after reflection it is evident they must intersect each other, and the points of intersection will constitute a curved line, which is termed a *caustic*, or sometimes a *caustic by reflection.*

To exhibit this curve, fill a wine-glass nearly full with milk, and place it so that it may receive the direct light of the sun or of a lamp as represented in figure 162. The light will be reflected from the concave surface of the glass, and form the curve upon the surface of the milk. The same effect will be produced if a piece of card is fitted accurately into the glass a little below the top.

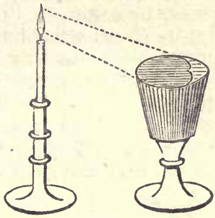
Fig. 162.

349. *Formation of Images by Reflection.*—The surface of a body, as we have seen, may be considered as made up of points; and to see this surface is to see all these points, each of its proper colour, and in its proper position, with reference to all the others. So, to form an image of an object, is to form an image of all its points in their natural position; and an image of a point is formed when all, or only a part of the rays emanating from it are again collected and reflected to the eye.

350. There are, however, two kinds of images of objects, which in some respects are quite different from each other. The first kind is merely a reflection to the eye of a portion of the light that proceeds from an object, as the image of an object seen in a common mirror or looking-glass. Here no screen is needed,

Quest. 348. What is illustrated in figure 162? 349. If the surface of a body may be considered as made up of many points, what is it to see a body? 350. How many kinds of images of bodies are there? What is the first kind? How must the observer be situated in reference to the

but the observer must be so situated as to see the surface of the reflector behind which the image seems to be situated. The second kind of image is generally formed upon a screen of some kind, as a piece of paper, or cloth, or the surface of ground glass. In this case the reflecting surface may be entirely concealed from view; it is only necessary that the surface on which the image is formed should be visible. To illustrate more clearly what is meant, let a person observe the reflection of a window on the opposite side of a room in a common looking-glass; this is an image of the first kind. Then let him darken all the windows in the room but one, and hold a pair of spectacles from 10 to 20 inches from the wall on the side of the room opposite this window, so that the light from the window may pass through one of the glasses to the wall. As soon as he gets the spectacles at the proper distance from the wall, a diminished but most beautiful image of the window will be seen upon the wall, which in this case constitutes the screen. This is the second kind of image referred to. In the first instance, the image of the window is seen only by looking on the face of the mirror; and, indeed, as stated above, it consists merely of the light from the window reflected to the eye; but, in the second, an image of the object is actually formed upon the wall of the room, and the eye observes it as a new object.

351. From what has already been said of the plane mirror, (§ 344), it necessarily follows that the image of an object seen in it will always appear erect and of the natural size, and situated just as far behind the mirror as the object is in front of it. Let it be constantly borne in mind that the light by which an object is seen emanates from each point of that object, and diverges as it advances until it reaches the eye.

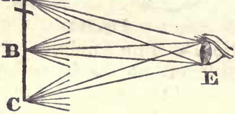

Fig. 163.

Thus, in figure 163, let A B C be three points of an object, as a cross, which is seen by the eye, E. From these three points (as well as from every other point of the object) rays are thrown off in every direction, diverging as they proceed; but a small pencil of those from each point is intercepted by the eye, and by this pencil that individual point is seen. Thus, from each point of an object, a cone of rays may be supposed to be formed, the base of which is at the pupil of the eye, and the apex at the point from which the rays

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mirror, in order to see the image? What is an image of the second kind usually formed upon? May an image of this kind be observed when the mirror itself is entirely concealed from view? How may the two kinds of images be shown by means of a mirror and a common burning-glass, in a room with a single window? 351. Where will the image of an object seen in a plane mirror always appear to be situated? By what is each point of an object seen? Must each point be seen by its own independent cone of rays?

emanate. Each point, therefore, of the object, is seen by its own independent cone of rays; and, to see the whole assemblage of points of the surface of the body next the eye of the observer, is, as before observed, to see the object.

352. It will be easy now, it is believed, to understand the manner in which images are produced by the plane mirror. As this mirror reflects diverging rays equally divergent as before reflection (§ 344), the only effect of the mirror on the cones of rays from the several points of the object will be to turn them all precisely alike out of their course, and thus change the apparent place of their origin; or, in other words, change the apparent place of the object.

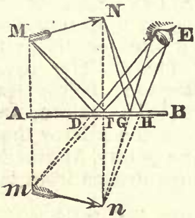

Fig. 164.

Let A B, figure 164, be a plane mirror; M N, an object placed before it; and E, the eye of the observer; then, of all the rays emitted from the two points M and N, and subsequently reflected from the mirror, those only can reach the eye which are so situated with respect to it, and the points M N, that the angles of incidence and reflection will be equal. Suppose the cones of rays, M D F and N G H, to be so situated; they will be reflected to the eye precisely as diverging as before; and if they are continued backward, they will seem to originate in the points *m* and *n* respectively. And as the rays diverge equally before and after reflection, the points *m* and *n* will appear just as far behind the mirror as M and N are in front of it. The image of an object, therefore, seen in a plane mirror, is always of the same size as the object, and is situated just as far behind the mirror as the object is in front of it.

353. Images of the first kind (§ 350), are formed by concave and convex mirrors in the same manner as by plane ones; but those produced by the convex mirror are always smaller than the object. The reason of it may be shown without difficulty. Let A B, figure 165, be a convex mirror, and D F an object in front of it. If, now, rays are supposed to emanate from the object, a portion of them from each point will be intercepted by the mirror, and reflected to the eye at E; but, as they are made by the mir-

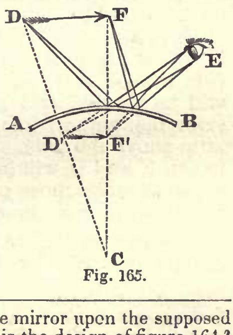

Fig. 165.

Quest. 352. What will be the effect of the plane mirror upon the supposed cone of rays from each point of an object? What is the design of figure 164? 353. May images of the first kind be formed by concave and convex mirrors? Will the image of an object seen in a convex mirror be smaller or larger than the object? Where will it appear to be situated?

ror to diverge more than before reflection, they will appear to emanate from a point behind the mirror nearer to it than the object is in front. The point D will appear at D′, and the point F at F′; the image being smaller than the object. The points D′ and F′ will always be situated in lines drawn from D and F to C, the centre of convexity of the mirror.

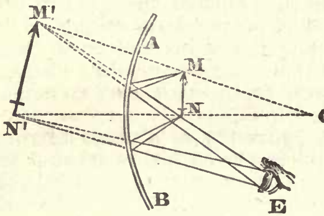

Fig. 166.

354. When an object is placed nearer a concave mirror than its principal focus, an image is formed by it in the same manner; but it is larger than the object. Let A B, figure 166, be a concave mirror, and M N an object in front of it, nearer than its principal focus. The rays, after reflection, being less divergent than before, the image of the object will appear farther from the mirror than the object is, and larger. The rays from the points, M and N, will appear to originate at M′ and N′, in lines drawn from the centre, C, through M and N respectively.

355. By means of the concave mirror, images may be formed which we have described above (§ 350), as images of the second kind. Let E A, E G, and E B, figure 167, be three rays emitted from the point, E, of an object, E D, in front of a concave mirror, A B, and farther from it than C, its centre of concavity. The ray, E G, being incident upon the mirror at its centre, will be reflected just as much below the axis G H as E G is above it; and to the same point will both the other rays from E be reflected. An image of the point E, therefore, will be formed at E′, a little below the axis, H G; and, in the same manner, an image of the point D will be formed at D′, a little above the axis. So, the images of the several points between E and H will be arranged in their proper order below the axis, while those of the part D H will be above the axis, the whole forming an inverted image of the object, E′ D′.

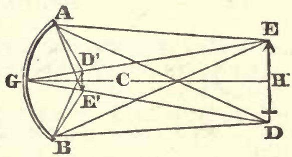

Fig. 167.

The size of the image E′ D′ will be as much less than that of the object E D, as its distance from the mirror is less. That

Quest. 354. Where, in reference to the concave mirror, must an object be situated in order that an image of this kind may be seen in it? Will it be larger or smaller than the object? 355. In figure 167, if an object be placed at E D, where will the image of the points, E and D, be formed?

is, the size of the image will be to that of the object, as the distance of the image from the mirror is to the distance of the object.

If the object is placed at E′ D′, its image will be painted on a screen situated at E D, and will be as much magnified as it was diminished in the former instance. In this case also the image will be inverted in reference to the object. In both cases, it will be observed, the image and object occupy the places of the conjugate foci (§ 346) of the mirror.

If an object is placed exactly in the focus of parallel rays, no image can be produced, since all the rays will be reflected parallel (§ 345); if placed nearer than this, they will be made to diverge after reflection, and of course no image can be formed in front of the mirror.

356. Experiments illustrating these principles can easily be performed by means of a lighted candle in a dark room, and any concave mirror of sufficient size. Having placed the mirror in a proper position upon a table, let the candle be placed near it as at D′ E′, figure 167, but a little one side of its axis; then let a screen, as a sheet of white paper, be held at a distance, as at E D. If a perfect inverted image of the flame is not at once seen upon the paper, it will be because its distance from the mirror is either too little or too great, and it is to be moved backward and forward until the image becomes distinct. It will be much larger than the flame.

Let the candle now be removed to a distance from the mirror, and placed at E D, the centre of the blaze being at the same height as the centre of the mirror, and let the sheet of paper be held at the other conjugate focus, E′ D′. In order that the light from the candle may not be intercepted by the paper, the candle must be placed a little on one side of the mirror's axis, and the paper held a little on the other side. The distance of the paper from the mirror must also be accurately adjusted in order to obtain a perfectly distinct image. As before, the image will be inverted, but it will be much smaller than the object itself. If the size of the images in the two cases are accurately measured, they will be found to be just in proportion to the distances of the screen from the mirror where they were formed respectively.

357. By means of a concealed concave mirror of a large size, various illusions have sometimes been practised.

Will the image be erect or inverted? How will the size of the image compare with that of the object? If the object were placed at E′ D′, where would the image be formed? Would it be larger or smaller than the object? Will an image be formed when the object is in the focus of parallel rays? 356. How may experiments be performed to illustrate the mode in which images are formed by means of the concave mirror? 357. How may the image of an object be formed so as to be visible to the observer when both the mirror and object are concealed?

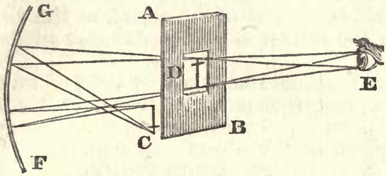

Fig. 168.

Let G F, figure 168, be a large concave mirror, not less than a foot in diameter, and let A B be a portion of a screen concealing it from the direct view of the observer, but having an opening in it exactly in front of the mirror. An object, as a bunch of flowers, is then placed inverted at C, and strongly illuminated by a lamp, which, however, must not cast its light upon the mirror. Both the flowers and the lamp are also concealed from the spectator, whose eye is supposed to be at E. He will, however, see a beautiful image of the flowers erect at D, in the opening in the screen; but, upon his attempting to lay hold of them, a dagger, or some other object, to his utter consternation, instantly takes their place. This is done by a person behind the screen instantly removing the flowers, and substituting a dagger in their place.

358. Besides the mirrors described above, others of different forms are sometimes constructed, but they always form distorted images of objects. Of this kind are cylindrical and conical mirrors, the names of which sufficiently indicate their forms. The effect of a cylindrical mirror may be seen by taking a bright sheet of tin-plate in the two hands, and slightly bending its two opposite sides backward, and observing the image of the face in it. Every part of the face will appear of the full length, but will be diminished in breadth, giving the whole a ludicrous aspect. If the upper and lower sides of the plate are bent backward, the reverse effect will be produced; the parts of the face will appear of the usual breadth, but greatly diminished in length.

359. Sometimes distorted pictures of objects are made, so that seen in one of these mirrors, all the parts of the object shall appear in their true proportions. Thus, let A, figure 169, be a cylindrical mirror, standing perpendicularly upon the paper, and let the figure, B C D E, be observed as it will be reflected from its surface. It will then appear as a perfect square, F, the distortion in the picture being necessary to give it this form after reflection from a cylindrical surface.

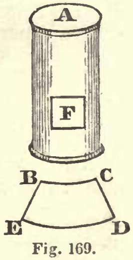

Fig. 169.

Quest. 358. May mirrors of other forms, besides those already described, be constructed? What is said of the images formed by them? How may the effect of a cylindrical mirror be familiarly shown? When will the parts of the face be diminished in length, and when in breadth? 359. What must be the form of a figure that will produce a square when viewed in a cylindrical mirror? What are these changes of form sometimes called?

Fig. 170.

Figure 170 represents a cylindrical mirror, A B, with a distorted figure, M N, in front of it, the image of which in the mirror assumes the appearance of a regular portrait.

The changes of form produced in this way are sometimes called *anamorphoses.*

REFRACTION OF LIGHT.

360. We have heretofore seen that a ray of light usually moves in a straight line; but this is the case only while it is passing in the same uniform medium, as through the air; when it passes obliquely from one medium to another, as from air to water or glass, or from either of these into the air, it is bent more or less out of a straight line, and is said to be *refracted.* But if the ray passes perpendicularly from one medium to the other, it is not then refracted.

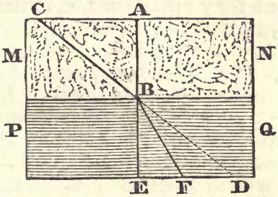

Fig. 171.

Let M N and P Q, figure 171, be two media, lying in contact with each other, the lower of which is most dense, and two rays, as A B and C B, passing through them. A B, being perpendicular to the surfaces of the media, will not be bent out of its course, but will proceed in a straight line to E; but the ray, C B, on arriving at B, instead of continuing a straight course to D, will be bent downward, and take the direction B F; that is, it will be bent or refracted *towards* the perpendicular, B E. On the other hand, when a ray passes obliquely from a dense to a rare medium, it will be refracted *from* the perpendicular. Let the ray be supposed to pass from F to B, when it arrives at B, it will be bent downward from the perpendicular B A, and take the direction B C. When the ray

Quest. 360. What will be the effect when a ray of light passes obliquely from one medium to another of different density? Will the ray be refracted when it passes perpendicularly from one medium to the other? When the ray passes from a rare to a denser medium, in what direction is it refracted?

passes from the rare medium, M N, to the denser medium, P Q the angle, A B C, is called the angle of incidence, and F B E the angle of refraction; but, if it passes in the opposite direction, then F B E is the angle of incidence, and A B C the angle of refraction.

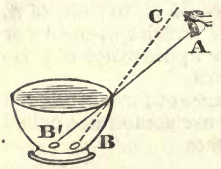

Fig. 172.

The refraction of light may be well illustrated by a well-known simple experiment. Place a piece of money, B, figure 172, in an empty basin, and stand by the side of it, having the eye at A, just so that the money may be concealed by the side of the vessel. Then let an attendant pour in water, and the money will be seen gradually to come into view, and to appear as if situated at B′ instead of B. The ray of light from B, after the vessel is filled with water, in passing from the dense medium, water, to the air, which is much less dense, instead of passing directly to C, as it did before the water was poured in, is now bent downward, and proceeds to the eye at A. But, as an object always appears to be situated in the direction of the ray when reaching the eye, the piece of money will now appear to be at B′, as stated above.

It is in consequence of refraction that a spoon in a tumbler of water always appears bent at the surface; the rays of light from the part above the water come directly to the eye, but those from the part beneath the water, being bent downward as they enter the air, cause that part of it to appear elevated above its true position; and of course it will seem to be bent just at the surface.

361. All substances do not refract light equally, some possessing the power of bending it much more out of its original course than others; but it is always to be remembered that in any particular case the amount by which the ray will be bent out of its course will depend upon the nature of the medium it leaves, as well as upon that of the medium it enters. Thus, a ray passing from air into glass, is more bent out of its course than when passing from water to glass; so when the ray passes from glass to air, it is bent more from a straight line than when passing from glass to water. As air is always present, when the refracting power of a substance is spoken of, if nothing is said to the contrary, the light is supposed to pass from air into it, or the reverse.

In what direction is the ray refracted when it passes from a dense to a rare medium? By what familiar experiment may the refraction of light be illustrated? Why does the object become visible as the water is poured in? Why does a spoon in a tumbler of water appear broken at the surface? 361. Do all bodies refract light equally? Will a ray of light be most bent out of its original course in passing from air to glass, or from water to glass?

362. Light is often irregularly refracted by passing through a medium, the density of which is not uniform. It is the change of density that often causes the appearance of veins and irregularities in glass and other transparent substances.

Every one has noticed the peculiar wave-like motion that seems to be going on in the air by the side of a hot stove or stove-pipe; it is best seen by attempting to look directly by the stove to some object, as a window, beyond it. This is occasioned by the unequal refracting powers of different portions of the air, as they are expanded unequally, and put in motion by the heat. The rays of light, in passing through air in this state, are indeed but slightly bent out of their direct course, but it is distinctly perceptible to the eye.

The same appearance is sometimes, though rarely, observed in the open air, in peculiar states of the atmosphere, in the warm weather of summer.

363. When light traverses a medium, the density of which varies uniformly, it describes a curve. This is the case with the light of the heavenly bodies in passing through the earth's atmosphere, so that we never see them in their true places, except when they are directly over our heads.

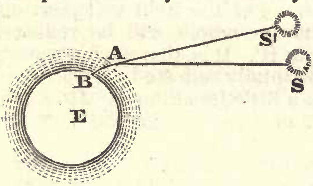

Fig. 173.

Thus, let S, figure 173, be the sun in the horizon, and E, a section of the earth with the atmosphere surrounding it. As the atmosphere is much more dense near the earth than at a distance from it (§ 217), a ray of light from the sun in or near the horizon, after entering it, as at A, will gradually be bent downward as it approaches the earth. A spectator at B, therefore, instead of seeing the sun at S, its true place, will see it considerably higher, as at S′. It is found that in consequence of the sun's apparent elevation from this cause, he actually appears above the horizon at rising about three minutes earlier, and, at setting, remains the same time longer, than he otherwise would, thus increasing the length of the day about six minutes.

Quest. 362. How is light affected in passing through a medium of varying density? How is the wave-like motion, often seen in the air by the side of a heated stove, accounted for? Is the same appearance sometimes observed in the open air? 363. What is the course of a ray of light in passing through a medium, the density of which varies uniformly? How is the light of the sun affected by the earth's atmosphere? Do we ever see the heavenly bodies in their true places? Do we see the heavenly bodies when near the horizon above or below their true places? How much longer does the sun appear above the horizon at setting, in consequence of refraction, than he otherwise would?

364. Bodies seen in the horizon in peculiar states of the atmosphere, sometimes appear singularly elevated by this cause above their proper natural position, and are said by sailors to *loom up.* A ship at a distance, or an island with the buildings upon it, will perhaps appear twice their ordinary height above the surface of the sea, while their other dimensions remain as usual. This is occasioned by the unusually great refracting power of the atmosphere, by reason of the temperature and the presence of other substances, as vapors, floating in it. The writer has often observed this appearance in a striking manner on the coast of New England, just before the commencement of severe snow-storms.

365. *Total Reflection of Light.*—A ray of light cannot pass from a dense to a rare medium, but is totally reflected, whenever the angle of incidence exceeds a certain magnitude, depending upon the nature of the medium.

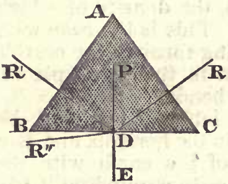

Fig. 174.

Let A B C, figure 174, be a section of a prism of glass, and R a ray of light entering it perpendicularly and incident upon the inner surface, B C, at D; if the angle of incidence, P D R, is greater than 41° 48′, none of the light will pass out at D, but the whole will be reflected upward to R′. It is, therefore, properly said to be totally reflected. If the angle, P D R, is a little less than 41° 48′, a portion of the light will pass out at D, and take the direction D R″.

The brilliancy of light, when totally reflected, far exceeds that reflected from the most perfect mirrors. To show this, let a tumbler nearly filled with clear water, be held up so that the upper surface of the liquid may be seen from beneath; it will appear of a beautiful silvery whiteness, by reason of the total reflection of the light incident upon it, and no object held above it will be visible through it.

366. *Progress of Light through different Media.*—The progress of a ray of light through any medium of uniform density may always be easily traced by means of the foregoing principles, and the result determined.

In passing through a pane of glass, or any medium bounded

Quest. 364. When are distant bodies said by sailors to *loom up?* How is this appearance occasioned? Under what circumstances is this phenomenon often seen on the coast of New England? 365. What is meant by the total reflection of light? What is the greatest angle of incidence a ray of light can have in passing from glass into the air? What will be the effect if the angle of incidence is greater than 41° 48′? What is said of the brilliancy of light when totally reflected? How may this be shown by means of a tumbler of clear water? 366. Will the foregoing principles be sufficient to determine the course of a ray in passing from one medium to another? Is the direction of a ray changed in passing a pane of glass which has its two plane

by two parallel plane surfaces, the direction of a ray of light is not changed, but its position is more or less altered.

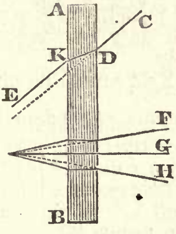

Fig. 175.

Thus, let A B, figure 175, be a piece of plate glass, the surfaces of which are perfectly parallel, and let C D be a ray of light incident at D; it will, on entering and leaving the glass, be refracted, according to the laws already stated (§ 360); but both refractions will be exactly equal in amount, and in opposite directions; that is, it will be bent upward at D, and downward by an equal amount at K; so that K E will be parallel to C D. It is, however, moved a little to one side from its former position, by the distance, in the present case, between K E and the dotted line extending from D. This distance must always be less than the thickness of the glass. The effect of this upon converging rays is to prevent their coming to a focus as soon as they otherwise would. Let F G H be several converging rays; it will be seen by tracing their course, that after emerging from the glass, they are removed a little farther from each other than they were before, and must proceed a little farther before meeting. Diverging rays are, in the same manner, brought a little nearer together.

367. If the two surfaces of the glass where the light enters and leaves it are not parallel, the ray will be bent more or less out of its course.

Let A B C, figure 176, be the section of a triangular prism, of which A C and C B are the refracting surfaces, and A B the base. A ray of light, D E, from a luminous body, D, on entering the glass, will be bent downward in the direction E F; and again, on escaping into the air, it will be bent downward in the direction F G; so that both refractions turn it from its original course in the same direction. If an eye is situated at G, the object, D, will appear to be at *d*, in the direction of G F produced.

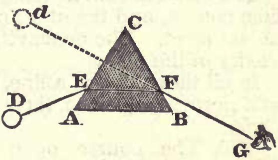

Fig. 176.

368. Instead of a solid glass prism, as represented above, one

surfaces parallel? Will the refraction of the ray, as it leaves the glass, be just equal to that which took place as it entered? Will converging rays come to a focus as soon after passing through a glass of this kind as they otherwise would? What will be the effect upon diverging rays? 367. If the two surfaces are not parallel, what will be the effect? What is shown in figure 176? Where will the object appear to be situated to an eye at G? 368. Is a solid glass prism necessary for this experiment? How may a

may easily be formed for the purpose, by having a frame made of tin, or even of wood, and puttying in three pieces of glass, and filling it with water or other transparent liquid. Or it will answer for many experiments if made with only two sides, with the space between them filled with water.

Other effects produced by the prism upon light are to be noticed hereafter.

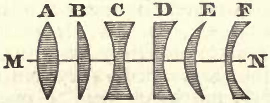

Fig. 177.

369. Instruments used for forming images by the refraction of light are called *lenses.* They are usually made of glass, or other transparent mineral substances, and are of various forms, as shown in figure 177.

The *double convex* lens, A, is a solid, bounded by two convex surfaces.

The *plano-convex* lens, B, is merely half a double convex, one surface being convex, as in the double convex lens, but the other plane.

The *double-concave* lens, C, has both its surfaces concave, like a solid formed of two watch-glasses placed back to back, and the space between them filled up with transparent matter.

The *plano-concave* lens, D, has one of its surfaces concave and the other plane.

The *meniscus*, E, is a lens having one surface convex and the other concave, and these curves meet if produced. The convexity of one surface exceeds the concavity of the other.

The *concavo-convex* lens, F, like the meniscus, has one surface convex and the other concave, but if produced, the curves *do not* meet. The concavity of one surface exceeds the convexity of the other.

In all these lenses, a line, M N, passing through their centres and perpendicular to their surfaces at this point, is called the *axis.*

370. The course of a ray through any one of the above lenses may be easily traced in the following manner. Let A B C D, figure 178, be a spherical lens, which is only a particular form of the double-convex, and M N O be three parallel rays incident upon it. The middle

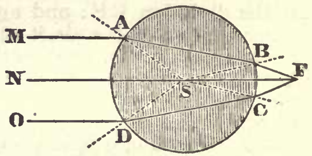

Fig. 178.

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prism be fitted for the purpose? 369. What are *lenses?* What are they usually made of? What is the form of the *double-convex* lens? What is the *plano-convex* lens? What is the form of the *double-concave* lens? The *plano-concave?* What is the form of the two surfaces of the *meniscus?* In what does the *concavo-convex* lens differ from the meniscus? What is the *axis* of a lens? 370. Why will not the middle ray, N, figure 178, be re-

ray, N, being perpendicular to the surface, will not be refracted in passing through the lens; but the rays, M and O, on entering the lens at A and D (being refracted towards the perpendiculars, A S and D S), will be made slightly to converge; and, on leaving the lens, (being refracted *from* perpendiculars at the points B C, will be made to converge still more; and the result will be to bring them to a focus at F.

The effect of the double-convex lens is precisely the same as that of the sphere, but somewhat less in degree. It is to collect the rays.

371. The distance of the focus of parallel rays from the convex lens depends upon the degree of convexity. In the double-convex lens of glass, it is at the distance of the centre of the sphere of which the lens is a part; but, in the plano-convex lens, the focus is at the distance of the diameter of the sphere, or twice the radius.

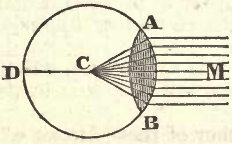

Fig. 179.

Let A B, figure 179, be a double convex lens, having each of its faces a portion of the surface of a sphere whose centre is at C, then this will be the point to which parallel rays, M, will be made to converge. If one side was plane, then parallel rays would converge to the point, D, at the distance of the diameter of the same sphere.

372. If the rays are converging before entering the double convex lens, the focus will be nearer the lens than the centre C, but if they are diverging, it will be farther from the lens. The same effect will also be produced upon the focal distance of the plano-convex lens.

The well-known burning-glass is usually a double-convex lens; and its effect, when held in the direct rays of the sun, is simply to concentrate the rays of heat, as well as those of light, to a point or focus. And the heat at this point is as much greater than the heat of the sun at the glass, as the surface over which it is distributed is less.

Burning-glasses of great power have sometimes been con-

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fracted in passing the spherical lens? In what direction will the rays, M and O, be refracted on entering the lens and on leaving it? What will the result be? Is the effect of the double-convex lens the same? Upon what does the distance of the focus from the lens depend? What is the distance of the focus of a double-convex lens? What is the distance in a plano-convex lens? 372. If the rays are converging before entering the lens will the distance of the focus be greater or less than if they were parallel? What is the common burning-glass? What is its effect when held in the direct rays of the sun? How much greater is the heat in its focus than the heat of the sun before being concentrated? What was the diameter of Mr. Parker's great burning-glass? Why was a second lens used with it? What is said of the heat capable of being produced by such an instrument?

structed. One made by Mr. Parker was three feet in diameter, and had a second smaller lens connected with it in order to diminish the diameter of the focus. The heat of the sun when concentrated by it was so great as to be capable of melting the less fusible metals, as gold and platinum, and other refractory substances. Indeed, such an instrument is perhaps capable of producing as great a heat as can be produced by man by any other means.

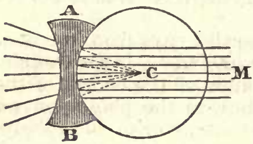

Fig. 180.

373. The effect of the double-concave lens is to disperse the rays of light. Let A B, figure 180, be a double-concave lens, having both its surfaces portions of equal spheres; and suppose parallel rays, M, to be incident upon it in the manner shown. These rays will be made to diverge by passing through the lens, and to appear to proceed from a point, as C, which is therefore called the *virtual* or *apparent* focus.

The effect of the plano-concave lens, it is easy to see, will be the same as that of the double-concave, but only less in degree.

The effect on converging rays by either of these lenses will depend upon the degree of their converging; if they are very converging, they may still converge after passing the lens, but in less degree; but, if their convergency is not great, they will either be parallel, or be made to diverge after passing it.

Diverging rays will be made still more diverging.

The action of the meniscus is the same as that of a double-convex lens of the same focal distance, the effect of the convex side in converging the rays being greater than that of the concave side in separating them. So the effect of the concavo-convex lens is the same as that of the double-concave lens.

374. *Formation of Images by Lenses.*—Images are formed by lenses much in the same manner in several respects as they are by mirrors. As we have before seen (§ 351), rays of light are emitted from every point of a visible object; and when the object is so arranged with reference to a convex lens that a portion of these rays from each point are again united in regular order, an image of it will be formed.

Quest. 373. What is the effect of the concave lens upon rays of light? What is its virtual or apparent focus? What will be the effect of a concave lens upon converging rays? How will diverging rays be affected? What is said of the action of the meniscus? 374. When will an image of an object be produced by a convex lens? May we consider the images of all the points of the object to be formed separately? What will be the position of the image in reference to the object?

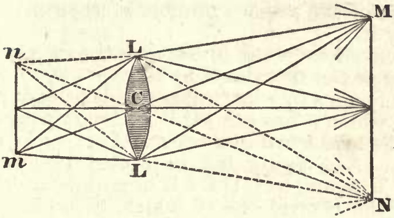

Fig. 181.

Let L C L, figure 181, be a double convex lens, and M N an object in front of it. From every point, as M, rays are emitted in every direction; but a cone of them represented by M L L, is intercepted by the lens, and again united at *m*, forming there an image of the point M. In the same manner, by a cone of rays emitted from N, an image of this point will also be produced at *n*; and thus an image of all the points of M N will be formed in *m n*, in their proper order, though in an inverted position, in reference to the object.

375. The size of the image, as compared with the object, will depend entirely upon its distance from the lens, compared with the distance of the object. If the object is at a great distance, the image will be near, and will be much smaller than the object; but if the object is near the lens, the image will be formed at a distance, and will be larger and less distinct than before.

An easy experiment illustrating these points may be readily performed in the evening, or in a darkened room, by means of a candle and a common magnifying-glass, or one lens of spectacles used by an aged person.

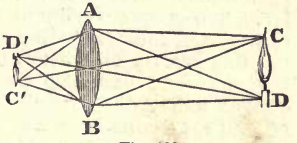

Fig. 182.

Suppose A B, figure 182, to be a glass of this kind, and C D the flame of a candle placed at a considerable distance from it. As before explained, a diminished and inverted image of the flame will be formed on a piece of white paper held at C′ D′. If, now, we place the candle at C′ D′, and the paper at C D, an inverted but enlarged image of the candle will be formed upon it. It is to be observed that, whatever may be the diameter of the lens, it does not affect the magnitude of the image; this depends entirely upon its convexity. Two lenses, therefore, of the same convexity, will form images of the same size, though one lens may be larger than the other; but the image of the larger lens

Quest. 375. Upon what will the size of the image, as compared with the object, depend? When will the image be smaller than the object? and when larger? How may experiments illustrating these principles be readily performed? Will the magnitude of the image depend in any degree upon the diameter of the lens? Will two lenses of the same convexity form images of the same magnitude, whatever may be their comparative diameters? Why

will be brightest, because of the greater number of rays from the object intercepted by it.

The effect of the concave lens being to disperse the rays of light, it is evident no image can be formed by it.

376. The formation of images by spherical lenses is attended by a practical difficulty which it has not yet been found possible entirely to avoid, called *spherical aberration.* Let A B, figure 183, be a very convex lens, and let C D E F G be parallel rays, the central one of which, E, being in the axis of the lens, will pass perpendicularly through it, without refraction. But the other four rays, being inclined to the surface of the glass, will be more or less refracted in passing through it, and, as before explained (§ 370), will be brought to a focus. But it will be seen, by a little examination of the figure, that the rays D and F nearest the axis are less inclined to the surface of the glass as they enter it than the exterior rays C and G; they will therefore be less refracted, and will form their focus farther from the glass than the exterior rays. The focus of the former rays will be at *n*, while that of the latter will be at *m*, where they will cross each other.

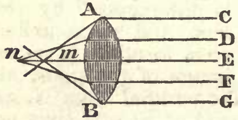

Fig. 183.

Now, if with such a glass we attempt to form an image of any object, the result of course is, that instead of a single well-defined image, the tendency is to produce several images at different points which will confuse, and, in a measure, destroy each other. This defect may, to some extent, be remedied in large lenses by covering all the lens except a small part at the centre, and thus excluding all the rays except the central ones, but this greatly diminishes the quantity of light. By means of the meniscus, and also by different combinations of plano-convex lenses, the difficulty may be in a great measure avoided, but no means have yet been devised by which, in the use of spherical lenses, it can be completely dispensed with.

377. To remedy this evil it has been proposed to construct lenses of other forms than the spherical; but the mechanical operations required in grinding and polishing them are so difficult that the project has been relinquished.

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will the image formed by the larger lens be brightest? Can images be produced by the concave lens? 376. What practical difficulty attends the formation of images by spherical lenses? When parallel rays pass through a convex lens, will all of them meet in the same focus? Are the rays near the axis of the lens or those farther from it brought to a focus nearest the lens? Will a single image be formed by such a lens? How may this effect be to some extent remedied? Have any means yet been devised by which it can be completely avoided? 377. Why has it been proposed to construct lenses of other forms? Why has the project been relinquished? Does spherical aberration take place also in concave mirrors?

Spherical aberration takes place also in concave lenses of every form.

In concave mirrors, likewise, of a spherical form, the same difficulty is to be encountered, but it is of less importance than in the case of lenses.

SEPARATION OF THE DIFFERENTLY COLOURED RAYS. —COLOURS OF BODIES.

378. White light, as it is emitted from the sun or other luminous bodies, is composed of rays of several different colours, which may be separated from each other. Newton, who first gave his attention to this subject, reckoned no less than seven colours as composing white light, viz: red, orange, yellow, green, blue, indigo, and violet, which he called *primary colours;* but the more recent investigations of Brewster have rendered it probable that the white ray of the sun contains only three rays, the red, the yellow, and the blue. The other colours of Newton are probably produced by different combinations of these three.

Newton's method of separating the several rays was by means of the triangular prism, which is only a solid piece of glass, bounded by three perfectly plane faces. Usually the faces are equally inclined to each other, but this is not essential.

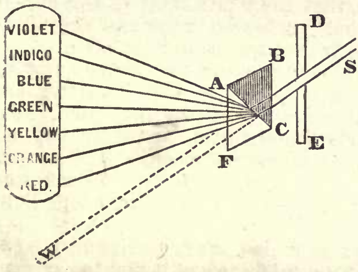

Fig. 184.

Let a ray of light from the sun, S, figure 184, be admitted through a hole in the window-shutter, D E, into a room from which all other light is excluded; it will form on a screen placed a little distance in front a circular image, W, of white light. Now, interpose near the shutter a glass prism, A B C, and the light, in passing through it, will not only be refracted, but the several colours of which white light is composed will be separated, and will be arranged in regular order on the screen immediately above the image W, which will disappear. The violet ray, it will be seen, is most refracted or bent out of its course, and

Quest. 378. What is white light, as it is emitted from the sun and other luminous bodies, composed of? How many coloured rays did Newton suppose enter into the composition of white light? What coloured rays only are contained in white light according to Brewster? How are the other colours of Newton produced? What was Newton's method of separating the several coloured rays? What is illustrated in figure 184? Which ray

the red least, while the other colours are between them; the whole forming on the screen an elongated image of the sun, called the *solar spectrum*.

The separation of the several rays is evidently occasioned by their different refrangibility, the glass of the prism having the power to turn some farther out of their course than others. But it is to be observed that these colours in the spectrum are not separated from each other by distinct and well-defined edges, but each runs into the other, the red shading off by imperceptible gradations into the orange, the orange into the yellow, the yellow into the green, &c.

Newton, indeed, and others since his day, have attempted to measure the width of the several colours in the spectrum; but, as might be expected, the results obtained by different individuals are far from being uniform. And it is now known that their apparent width, compared with the whole width of the spectrum, will greatly depend upon the particular kind of glass, or other transparent substance, which may be used. The results with a prism of flint-glass, for instance, will be different from those obtained when one of crown-glass is used; so also if a prism of water contained in a prismatic glass vessel (§ 368) is made use of, the results will be entirely different from those obtained with a prism of alcohol, or sulphuric acid, or solution of salt.

379. It appears, therefore, that the white light of the sun is composed of several differently coloured rays, and the effect of the prism is merely to separate them from each other.

It matters not in practice whether, with Newton, we consider there are seven differently coloured rays, or with Brewster that there are only three, since the results will be the same. If a second prism, A F C, precisely like the first, be placed beyond it, but in contact with it, and in a reversed position, the several rays which are separated by the first prism will be reunited by the second, and beyond it nothing but the pure white light of the sun will appear.

The several coloured rays may also be recombined by holding a convex lens near the prism between it and the screen, so as to bring them to a focus, which will be perfectly white.

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is refracted most, and which least? What is the *solar spectrum?* How is the separation of the rays occasioned? Are the colours of the spectrum separated by a distinct line? Will the width of the several colours be the same where prisms of different refracting substances are used? If hollow prisms filled with different liquids, as water and alcohol, are used, will the width of the colours be the same? 379. Is it important whether we consider that the solar beam is composed of seven coloured rays, or only three? How is it shown that the reunion of the coloured rays of the spectrum will produce white light? May the coloured rays also be reunited by a convex lens, so as to produce white light?

380. The same point may be illustrated further by mixing powders of the several different colours in the proper proportion, which will produce a greyish-white. A pure white cannot be produced in consequence of the impossibility of obtaining powders of precisely the proper shade.

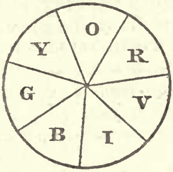

Fig. 185.

If we take a circle of wood, figure 185, and put a pin through its centre for it to revolve upon like a top, and divide it into sections R, O, Y, G, B, I, and V, of the proper proportions, by pasting upon it pieces of paper of the different colours of the spectrum, when it is made to revolve rapidly, the whole will appear of a grayish-white as before. The violet, V, is designed to occupy about 80 degrees of the circumference; the indigo, I, 80°; the blue, B, 60°; the green, G, 60°; the yellow, 40°; the orange, 27°; and the red, 45°; which, according to Newton, is the proportion of the spaces occupied by these colours in the spectrum.

381. Whether we regard the seven colours of Newton as simple or not, it is found impossible to produce any farther decomposition of any one of them by means of the prism. This is shown by making a small hole in the screen upon which the spectrum is formed, just sufficient for one of the rays to pass through, and placing behind it a second prism, by which it is a second time refracted, but no change of colour is produced.

382. On the undulatory theory, which has already been partially explained (§ 330), these different colours are supposed to be produced, not by rays of different colours, but by differences in the amplitude and rapidity of the vibrations in the universally diffused ether, occasioned by passing the prism. According to Sir John Herschell, the extreme red ray is produced by waves, or undulations, the length of which is 266 ten-millionths of an inch, and 458 millions of millions of them occur each second, while the length of the waves producing the extreme violet is only 167 ten-millionths of an inch, and 727 millions of millions take place in a second. In the other colours of the spectrum, both the length of the waves, and the number occurring in a second, are intermediate between the numbers above given for the red and the violet, the extreme rays of the spectrum.

383. The solar ray may also be decomposed by passing it

Quest. 380. How may the same point be further illustrated by means of paints? Can a pure white be produced in this way? What is the reason? 381. Can any one of the seven coloured rays of the spectrum, according to Newton, be decomposed by means of the prism? How is this shown? 382. How are the different colours of the spectrum produced on the undulatory theory? What is supposed to be the extent of the waves producing the extreme red ray of the spectrum? How many of them occur in a second? What is the length of the waves which produce the extreme violet, and how many occur in a second? 383. By what other means may the solar

through some medium that is capable of absorbing some of the rays and transmitting others. If, for instance, a beam of white light be passed through a clear blue glass, it emerges of a fine blue colour, having lost in the glass the rays which, when mixed with it, produced the white light. To determine what rays these are, it is necessary only to look at the solar spectrum through the glass; the red and the orange will then disappear, while the yellow will be greatly increased in width, occupying a portion of the space before covered by the orange on one side, and the green on the other. It appears, therefore, that the glass absorbed the red rays which, when mixed with the yellow, constitute the orange, and also the blue, which, with the yellow, constitute green.

By experimenting in this way with differently coloured media, it is found that there are in reality only three coloured rays in the solar spectrum, the red, the yellow, and the blue, and that certain mixtures of these produce the other colours. The solar spectrum may be considered as made up of three other spectra, one of red, one of yellow, and one of blue, which overlap each other. Each colour extends over the whole of the spectrum, but is much more intense in that part where that colour predominates. The red is most intense in the middle of the red space, the yellow in the middle of the yellow space, and the blue between the blue space and the indigo.

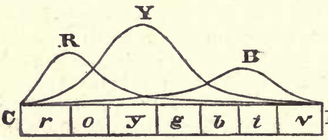

Fig. 186.

Let C H, figure 186, represent the solar spectrum, the letters *r*, *o*, *y*, *g*, *b*, *i*, *v*, indicating the place of the several colours of the spectrum, red, orange, yellow, green, &c. We may suppose the curves R, Y, and B, to indicate the relative intensities of the three supposed primary colours, red, yellow, and blue, and also the parts of the spectrum where each is most intense. Thus, the red, R, commences at C, and at once attains its greatest intensity, and then diminishes, becoming very faint towards H. The yellow, Y, likewise begins at C, but does not so soon attain its medium intensity, and extends farther towards H, while the blue, B, commences very faint at C, and becomes most intense near the other extremity of the spectrum, H. Neither the red nor the blue is as

ray be decomposed? If we look at the solar spectrum through a blue glass, what colours will disappear, and what colours will be increased in width? What is the occasion of this? By experimenting in this manner with glasses of other colours, what rays only, are we led to conclude, are contained in the solar spectrum? How are the other colours produced? Does each of these coloured rays extend over the whole spectrum? Where is the red most intense? Where the yellow? How is this illustrated in figure 186? What is

intense as the yellow, as is designed to be indicated by the curve Y rising higher than the others.

Each of the other colours, it will be seen, is composed chiefly of two of the primary colours, with a little of the third. Thus, the orange is made up of the red and yellow, with a very little of the blue, and the green is composed of a mixture of the yellow and blue, with a little red.

384. The green, because of its position in the spectrum, is sometimes called the *medium* or *mean ray;* but, though this colour is usually near the middle of the spectrum, it is found that the distance the extremes will be removed from it will depend upon the nature of the prism. A prism of hollow glass, filled with oil of cassia, for instance, will form a spectrum twice as long as one made of solid flint glass; and of course the two extremes will be removed at twice the distance from the mean. Hence, the oil of cassia is said to have a greater *dispersive power* than the glass, because it spreads or disperses the spectrum over a greater surface than the glass.

385. Flint-glass, which contains in its composition oxide of lead, has a greater dispersive power than crown-glass, which does not contain this ingredient. If, therefore, A B C, figure 184, be a prism of flint-glass, and A F C a similar one of crown-glass, though the spectrum will disappear, and the luminous spot, W, be reproduced, it will not be composed of pure white light, as was the case when two prisms of the same kind of glass were used (§ 379), but coloured on one side with red, and on the other with purple. This is occasioned by the unequal dispersive power of the two kinds of glass producing spectra of unequal lengths, though the mean ray is equally refracted by both, and therefore the luminous spot produced just where it was before.

386. But though some prisms expand the spectrum much more than others, they do not in such cases expand all the differently coloured bands equally. The oil of cassia prism, alluded to above (§ 384), will form a spectrum twice as long as one of flint-glass; but the violet and indigo bands will be much more expanded in proportion than the red and the orange. If two prisms, one of oil of cassia, and the other of sulphuric acid, are used, this difference, we are told, is very striking.

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said of the composition of each of the colours of the spectrum besides the three primary rays? What is the orange chiefly composed of? 384. Why is the green sometimes called the *mean ray?* Does it always occupy the middle of the spectrum? Will the length of the spectrum depend upon the nature of the prism used? What is said of the spectrum produced by a prism of oil of cassia? What is meant by the *dispersive power* of a prism? 385. What is said of the dispersive power of a prism made of flint-glass, as compared with one of crown-glass? If two prisms, similar in form, but one of flint-glass and the other of crown-glass, are combined as represented in figure 184, will white light be reproduced as when two prisms of the same kind of glass are used? What reason is given?

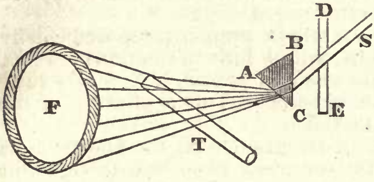

Fig. 188.

387. The solar spectrum furnishes the means of producing some of the most gorgeously coloured figures that can be presented to the eye. Let a ray of light, S, from the sun be admitted through a window-shutter, D E, of a darkened room upon a glass prism, A B C, as before (§ 378), and hold a little beyond it in the coloured ray a glass tube, T, about an inch in diameter, and there will immediately be formed upon the screen, placed at about 10 feet distance, an ellipse of the most beautiful colours, which will vary with every motion of the tube. The form will also vary as the tube is held more or less inclined in the ray, approaching, when it is held in one position, nearly to a circle, and when held in another position, becoming a very elongated ellipse.

If for the tube other transparent or reflecting bodies are substituted, regular figures of every conceivable form may be produced, all of them displaying the richest tints of the rainbow. A tumbler of cut glass partly filled with clear water, substituted for the tube, produces some of the most beautiful figures, while the slight motion of the water causes a flashing of the colours, occasionally not unlike the coloured Aurora Borealis, sometimes seen.

These experiments are easily performed, and equal in brilliancy anything that can be produced in the whole range of optical science. (*See Description* by Professor OLMSTED, in SIL. JOUR., Vol. XLVIII, page 137.)

388. *Fixed Lines of the Spectrum.* — When a narrow line of light is admitted through a slit in the window-shutter of a darkened chamber, and made to fall upon a good prism of glass, the spectrum thus formed will be crossed throughout its whole extent by dark lines of different breadths, which can be best seen by a telescope standing at the distance of some 10 or 12 feet. These lines can be better observed by looking at the narrow slit by which the light is admitted through the prism; and the effect is said to be considerably increased if a bottle of nitrous acid gas is interposed between the glass and the light.

None of these lines correspond to the boundaries of the different colours, though the whole number is not less than 600.

Quest. 387. What is said of the coloured figures that may be produced by means of the solar spectrum? How are these coloured figures produced as explained in figure 187? What is said of the flashing occasionally produced when a tumbler of clear water is held in the spectrum? 388. How may the fixed lines of the spectrum be seen? Are these lines always the same for

Perhaps the most important point connected with these lines is, their constancy for the same kind of light, or light from the same source. Thus, the spectrum formed by the light of the sun, whether derived directly or indirectly from their source, always exhibits the same lines; but almost every fixed star has its own system of lines. But the spectra formed by the light of the stars Sirius and Castor are precisely alike.

It is a little remarkable that the spectrum formed by lamp-light contains none of these dark lines; but in some cases distinct bright lines appear instead of them.

389. *Illuminating Power of the Spectrum.* — The greatest illuminating power of the spectrum appears to be in the yellow band, and from this it decreases towards both extremities. The best method to determine this point is to throw the spectrum upon a screen on which is some tolerably fine print, and observe where the print can be read most distinctly.

For a discussion of the heating rays, and also the chemical rays, which always accompany the several coloured rays of the spectrum, see author's *Chemistry*, pages 64 and 65.

390. *Colours of Bodies.* — The colour of a body is not the result of anything naturally inherent in the body itself, but depends upon its relations to light. Whatever may be the colour of a body, when held in the red ray of the spectrum, it is itself red; and when held in the blue, it is blue, &c.; the colour in any case being of course more brilliant when the natural colour of the body corresponds with the colour of the ray in which it is held. A red wafer, for instance, when held in the red, is red, and when held in the yellow, is yellow; but the red is more brilliant than the yellow, because the natural colour of the wafer corresponds with the colour of the ray. The colour of a body, therefore, is the colour simply of the light it reflects. A red substance is one that has the power of reflecting the red, while it absorbs or stifles all, or nearly all, the other rays; a green substance is one, the surface of which reflects the green, while it absorbs the other rays, and so of the other colours. The different shades of tints observed in bodies are all occasioned by different mixtures of the primary rays.

Bodies that reflect all, or nearly all the light which falls upon them, are white, while those that absorb nearly all are black. But probably no substance is capable either of reflecting or absorbing all the rays that fall upon them.

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light of the same kind? What is said of the lines seen in the light of different fixed stars? Are these lines seen in the spectrum formed by the light of a lamp? 389. Where is found the greatest illuminating power of the spectrum? 390. Upon what does the natural colour of a body depend? Will any body, whatever its colour, when held in one of the rays of the spectrum, appear of the same colour as that ray? Why will a red wafer, when held in the red ray, appear of a more brilliant colour than when held in any other ray? What then is the colour of a body? When is the colour of a substance said to be red? When is it said to be green? Upon what do the different shades of tint, observed in bodies, depend? When will a body be white? When black?

391. Newton attempted to account for the particular colour reflected by a body, by supposing it to depend upon the size of its particles. He found that on pressing a large convex lens upon a plate of glass, at the central point where the two pieces of glass touched, a black spot was produced, but immediately around this rings were formed, possessing all the different colours of the spectrum; and that the production of a particular tint depended upon the thickness of the stratum of air intervening between the glasses. So also, when soap-bubbles are blown very thin, they exhibit the same beautifully coloured rings, particularly around the top, just before they burst. In both these cases the different colours appear to be produced by the different thicknesses of the film of air, and of solution of soap, at the points where they are produced. Thus, in the experiment with the two glasses, at the centre where the glasses touch, the colour is black; but at a little distance where the film of air is of a certain thickness, a particular colour,—suppose blue,—is produced. Still further from the central point, where the film of air becomes of another determinate thickness, some other colour, as yellow, is seen; and so for every variation in the thickness of the film or plate of air, a different colour is produced. And as the apparatus is simply a double convex lens pressed upon a piece of plate-glass, it is evident, that at every given distance from the central point of contact, the films of air of the same thickness will constitute circles; the colours will be in the form of rings, as is always the case, unless the glasses are pressed together more on one side than the other.

392. It appears, then, that when certain substances are reduced to very thin plates, they have the power of decomposing light, and reflecting only certain of the rays, while the others are transmitted or absorbed; and, if we could obtain one of these plates or films of uniform thickness, its tint would be uniform throughout. Now, we may suppose all bodies to be composed of such films, which, though they are in contact, may still act upon light in the same manner as if they were separate. Their colour would, of course, be the colour of the light reflected by their external film, the thickness of which, we may suppose, would depend upon the size of the particles of the body. From this it follows, therefore, that the colour of a body will depend upon the size of its particles. But it is to be re-

Quest. 391. Upon what did Newton suppose the particular colour reflected by a body to depend? What did he find was produced when a convex lens was pressed upon a piece of glass with a plane surface? What does the production of a particular tint in this experiment depend upon? What is said of the colours produced when soap-bubbles are blown very thin? In these two experiments, will a particular tint be produced for any different thickness of the film of air or of solution of soap? Why, in the experiment with the lens and plate of glass, will all the several colours be arranged in circles? 392. If we could obtain a film of a transparent substance of uniform thickness, would its tint be uniform throughout? May we suppose all bodies to be composed of such films which act upon light just as if they were separated?

membered that this method of accounting for the particular colour reflected by a body is merely theoretical, and is not to be considered as established.

393. Some substances that are of themselves opake, or nearly so, become transparent, or at least translucent, by being moistened with some transparent fluid. Thus, common writing-paper, especially when tolerably thick, is quite opake; but it becomes very translucent when saturated with oil. This is occasioned by the filling of the pores of the paper with the oil, by which the light is transmitted, though it was incapable of passing these minute interstices when void, or filled only with air.

394. *The Rainbow* —The rainbow is a splendid natural phenomenon, consisting of a coloured arch apparently suspended in the sky, usually seen after a shower of rain in that part of the heavens opposite to the sun. When the circumstances are favourable there are always two bows, one within the other, the inner one being brightest, and therefore called the *primary bow.* The other is called the *secondary bow.*

395. The rainbow is also sometimes seen in the spray produced by a cataract, as at Niagara Falls, or by the dashing of the waves upon the shore of the ocean. But in all cases the cause is the same, viz: the decomposition of the light of the sun by the falling drops of water in the manner of the prism (§ 378), and its subsequent reflection to the eye of the observer. The position of the bow, whether seen in the drops of falling rain, or in the spray of the cataract, will always be on the opposite side of the observer from the sun; that is, in looking at the bow in front of him, he will have the sun behind him. On further examination, it will be found that the sun, the eye of the observer, and the centre of the circle of which the bow forms a part, will be in the same straight line.

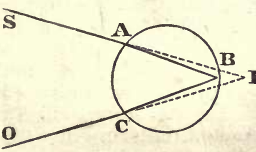

Fig. 188.

396. To understand the manner in which the light is decomposed and reflected to the eye, let us suppose A B C, figure 188, to be a drop of water suspended in the air, and S a ray of light from the sun to strike it at A. As the water is more dense than the air in which the ray

What then would be the colour of a body? What may we suppose the thickness of the films of a body to depend upon? Are we to consider this explanation of the colours of bodies as demonstrated? 393. How may some opake bodies be made translucent? Why does paper become translucent when its pores are filled with oil or water? 394. What does the rainbow consist of? In what part of the heavens is it seen? How many bows are seen when the circumstances are favourable? By what terms are these two rainbows distinguished? 395. In what is the rainbow sometimes seen? Is the cause always the same? Will the bow always be seen on the side of the observer opposite the sun? What is said of the relative positions of the sun, the eye of the observer, and the centre of the bow? 396. What will be the course of the ray in the drop of water as illustrated in figure 188? If it were possi-

has been moving, on entering the drop, instead of proceeding onward in a straight line to D, it will be bent downward to B, and then from the interior surface it will be reflected back to C; and on emerging into the air again at C, it will be bent upward and proceed to O, as if coming from D. Now, the white light of the sun's ray is always decomposed, more or less, when refracted; consequently, at A, some separation of the primary rays must take, which, however, will be increased at C. From a single drop, therefore, all the colours of the spectrum will be produced, the violet, as it is most refracted (§ 387), being highest, and the red lowest, with the other rays between them. If it were possible, therefore, to suspend a single drop of water in the air, as supposed, at the distance at which the bow is formed, and to receive on a screen in a dark chamber the several rays thus decomposed and reflected from it, we should form a solar spectrum, as perfect as that produced by the prism, only it would be exceedingly faint, because of the small quantity of light Now, if we place the eye in the solar spectrum produced by the prism, as a general thing, only one ray can enter, the other rays all passing either above or below the eye. So of the coloured rays separated by the drop of water in the air, only one of them could be seen by the eye while in the same position, but they could all be seen in succession by raising or depressing the eye.

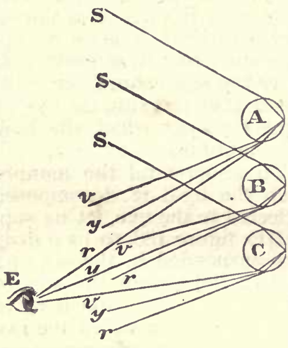

Fig. 189.

397. But let us suppose there are several drops placed side by side one above the other, as A, B, C, figure 189. To prevent confusion, we will trace the course of only three rays, the violet, the yellow, and the red. Let S S S be the rays of the sun, which will be parallel. From the uppermost drop, A, the several colours will emerge, as above described; but the violet and yellow will pass above the eye at E, the red only, which is least refracted, entering it. The drop, A, therefore, will appear entirely red. Of the rays from the next drop, B, the yellow only, we will suppose, enters the eye, the position of the drop being

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ble to suspend a single drop of water in the heavens at the proper distance, would it give all the colours of the spectrum? If the eye is placed in the solar spectrum formed by the prism, why will only one colour, as a general thing, be seen? Would only one of the colours produced by the drop of water be seen? 397. But if there are several drops perpendicularly over each other, what will be the effect? What three colours are supposed to be reflected to the eye from the three drops in figure 189? Why does the eye

such as to bring this to the eye, while the two extreme rays pass one above, and the other below it. This drop, therefore, will appear yellow. From the lowest drop, C, only the most refracted ray, the violet, will enter the eye; all the others not being bent upward sufficiently, passing below it. Its colour, therefore, would be violet. It will be seen, therefore, though the several coloured rays which emerge from each drop, reckoning downwards, would be in the order violet, yellow, and red, yet to the observer, looking at them in their position, this order would be reversed; and he would see the red highest, then the yellow below it, and then the violet lowest. Now this is the order in which the colours are always seen in the primary rainbow; the red occupies the highest or outside edge of the bow, and the violet the inside, the other colours being intermediate in regular order between them.

398. It is evident that in the production of the rainbow, drops of water cannot remain suspended in the air, as we have supposed, but the effect is the same. The drops are indeed constantly falling, but at any point from which a particular ray comes to the eye, they succeed each other with such rapidity, that the effect is the same, in decomposing the light, as if a single drop had remained suspended there.

399. Exterior to the primary bow, and at a distance from it, is the secondary rainbow, which is always less brilliant than the primary, and has the several colours in the reverse order. That is, in the secondary bow the violet is outermost, and the red on the inside edge, with the other colours in their proper order between them.

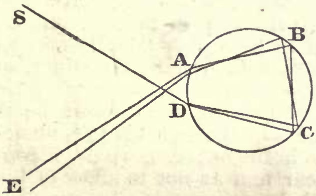

Fig. 190.

To understand the mode in which this is formed, let ABCD, figure 190, be a drop of water, and S, a ray of white light from the sun, entering it at D. On entering the water, by the law of refraction it will be bent upward to C, from which it will be reflected by the interior surface to B, and from that to A, where it will again emerge into the air, and will be bent downward to E, the several coloured rays being separated from each other as before. In this case, however, the red, being least refracted, will be uppermost, and the violet lowest. And if we suppose several drops to be ar-

receive only the red from the first or uppermost drop? And why is the violet ray only received from the lowest drop? What becomes of the other rays? What is the order in which the colours always appear in the primary rainbow? 198. Do drops of water actually remain suspended in the air in this manner? How then are the colours formed? 399. Where is the secondary rainbow situated in reference to the primary bow? What is the order of the

ranged above each other as before (§ 395), it is easy to see that the order of the colours must be the reverse of that in the primary rainbow, as is really the case in the secondary bow.

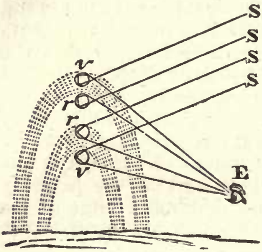

Fig. 191.

The position of the two rainbows, and the order of the colours in each, will be as represented in figure 191. SS are the rays of the sun, and E the eye of the observer. The extreme colours only, the red and the violet, are represented, the others being supposed in their proper order between them.

400. It will be observed that in the production of the primary rainbow the light undergoes two refractions, one on entering the drop of water, and the other on leaving it, and one reflection; but in the secondary bow it is twice refracted, once on entering the drop, and again on leaving it, as before, and twice reflected. Now at every refraction and every reflection, a portion of the light is necessarily lost; we see, therefore, why the colours of the secondary bow should be less brilliant than those of the primary, the light in producing it having to undergo one more reflection. Other rainbows, besides these two, are theoretically possible, in forming which the light must undergo more than two reflections in the drops of water, but the colours become by so many reflections too faint to be observed.

401. As the sun, the eye of the spectator, and the centre of the bow, must always be in a straight line, we perceive why the rainbow is seen in time of rain only in the morning or evening. Suppose a rain-cloud to pass over the observer as early as 3 o'clock in the afternoon, with well-defined edges, so that the sun makes his appearance as soon as, or even a little before, the rain has ceased falling at the point where he is standing; a line drawn from the sun through his eye, on account of the sun's being so high in the heavens, would, if continued, strike the ground so near him as not to allow of the formation of the bow.

The altitude of the sun above the horizon where the primary bow is seen by an observer situated upon the level surface of the earth, cannot be more than about 41 or 42 degrees; but if the observer be upon a high mountain, he may often see it formed below him when the sun is higher in the heavens. So,

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colours in the secondary bow? What is shown in figure 190? What is shown in figure 191? 400. How many reflections and refractions does the light undergo in producing the primary rainbow? How many in producing the secondary bow? Why is the secondary bow less brilliant than the primary? Are other rainbows possible? Why are they not seen? 401. Why is the rainbow seen only morning or evening? What is the greatest altitude

if the observer be on a plain, the magnitude of the bow cannot exceed a semicircle, but it is not so to a person on a high mountain.

Rainbows are sometimes formed by the light of the moon, but the colours are exceedingly faint, so as to be scarcely perceptible.

402. The *circles* often seen around the sun and moon are produced by different refractions and reflections of the light, in passing through the particles of moisture and other exhalations, contained in the atmosphere. Sometimes it is supposed they are occasioned by small crystals of ice, which are no doubt, even in warm weather, often produced by the cold which is known to prevail in the upper regions of the atmosphere. Sometimes several circles are seen at once around the sun or moon, but they do not usually have the same centre, which for each circle is at a little distance from the luminary. When there is but a single circle, the luminary always appears exactly in its centre. Not unfrequently, besides the circles surrounding the luminary, several other circles and parts of circles are seen crossing each other in various directions, some of which will have the luminary in their circumferences, and some will be at a distance from it, and apparently having no connection with it. To all these the term *halo* has been indiscriminately applied. *Mock suns* or *coronæ* appear to be usually only small fragments of arcs of circles, and are generally seen in pairs at equal distances from the sun, on opposite sides.

Fig. 192 is a representation of the halo which was seen in the State of Connecticut, and other parts of our country, about the middle of the day, September 9, 1844. It is made from a sketch taken by the eye at the time, the observer being supposed to face the south. Around the sun, S, were two distinct circles* not concentric with each other; and at A and B, above and below the sun, where these circles crossed or overlaid each other, were two bright coronæ. North of the sun, and having the sun in its circumference at the south, was the large circle S D C E, which was very distinct and fully formed. At C, the segments of two other circles appeared crossing each

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the sun can have when the primary bow is seen? If the observer is standing on a plain, what is the greatest magnitude the bow can have? May rainbows be formed by the light of the moon? 402. How are the circles often seen around the sun and moon produced? May crystals of ice exist in the upper regions of the atmosphere in places in warm latitudes? Are there sometimes more than one circle? What are *mock-suns?* Where was the *halo* seen represented in figure 192? Did any of these circles exhibit the

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* It is proper to state that in an article which appeared in the New Haven Palladium the next day after the occurrence of this phenomenon, these were described as a "circle accompanied by an ellipse of the same major axis, and of small eccentricity;" but, without attempting now to decide the question, the writer has thought best to follow his own notes made at the time.

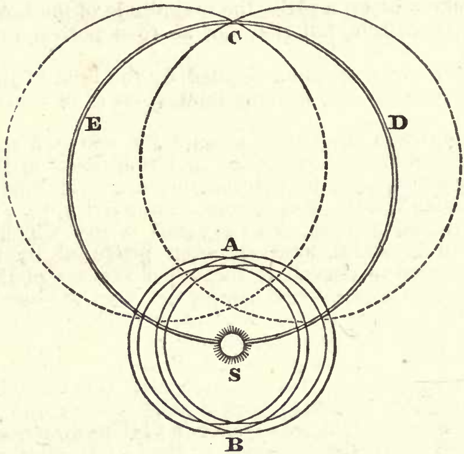

Fig. 192.

other, and also the circle S D C E. These segments were very distinct, but the rest of the circles, of which they formed a part, indicated by the dotted lines, though at times perceptible, were very faint. The two circles around the sun at times exhibited the colours of the rainbow with considerable vividness, but all the others were white. At Jackson, Tennessee, a combination of circles very similar to these was seen January 1st, 1824. (*Sil. Journal*, Vol. VII., p. 384).

403. A very singular phenomenon, called *mirage* or *fata morgana*, which is occasionally seen in different countries, appears to be occasioned by a peculiar state of the atmosphere in the place, the lower parts near the surface being much more dense, and of course refracting the light more (§ 360) than the parts immediately above. This, as we have seen, always takes place to some extent; but in some cases, from the operation of causes which are not altogether understood, the difference in the density of the lower and upper parts of the atmosphere becomes greatly increased; and rays of light from objects at the surface, which are at first emitted in a direction that would carry them high above the earth, are, by the unequal refraction of the different strata of the atmosphere, gradually bent so much out of their original course as to be again returned to

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colours of the rainbow? 403. What occasions the phenomenon called *mirage* or *fata morgana?* May the density of the air above us diminish so rapidly as to cause rays of light from distant objects that would otherwise pass over our heads to be brought down to the eye? Will an image of the object be then seen in the air? How is this illustrated in figure 193?

the surface. In such a case an image of the object will be seen, more or less elevated above the object itself, in the direction of the rays as they enter the eye (§ 360).

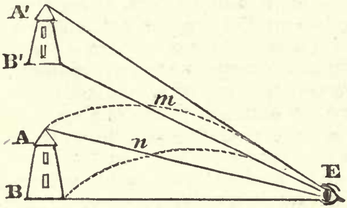

Fig. 193.

Thus, let A B be an object in the horizon seen directly by the eye, E, by the rays A E and B E, through the strata of air near the surface of uniform density. At the same time, rays will be emitted in other directions, as A m, and B n; and if the density of the air through which these rays pass diminishes with sufficient rapidity, they may be bent so much out of their original course as to be brought down to the eye, E, of the spectator, and he will see an image of the object in the air as A′ B′.

404. If the density of the air through which the ray B n passes, diminishes much more rapidly than that through which the ray A m passes, B n may be bent downward more than A m, so as to cross it; and then the image A′ B′ will be inverted. In many instances, a direct and an inverted image, one above the other, have been seen at the same time.

This phenomenon may occur when the object, the image or images of which are seen in the air, are below the horizon. Figure 194 represents a phenomenon of this kind, which was seen by Dr. Vince from Ramsgate, a small town on the coast of England. A ship was passing at such a distance, that only her topmasts, A, appeared above the horizon; but in the air above the ship were two perfect images of her, B, and C, the lower one of which was inverted and the other erect, the keels of the two being together. In another case of the kind, there appeared a portion of the sea between the two images.

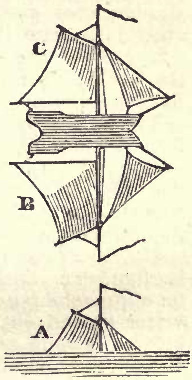

Fig. 194.

In 1822, a young English captain, being at sea, observed the inverted image of a ship in the air, which was so distinct that he recognised it as the one commanded by his father, though the ship at the time was entirely out of sight below the horizon.

Quest. 404. Under what circumstances will the image appear inverted? May this phenomenon occur when the object, the image of which is formed in the air, is below the horizon? What is represented in figure 194? What is said of the English sea-captain?

405. The ship that was seen coming into the harbour of New Haven, Connecticut, in the month of June, 1647, was, no doubt, an instance of this kind. This town was first settled in 1637; and only 10 years afterwards, with much effort, the citizens fitted out their first ship of about 150 tons, which sailed for England in January, 1647. This was of course to them a matter of great importance, especially as she took as passengers several of their first inhabitants. On the opening of spring they were greatly disappointed to learn by arrivals from England that nothing had been heard of her there, and of course were in a dreadful state of suspense with regard to her. In the month of June, after a severe shower of rain, attended with lightning and thunder, a little before sunset, it was announced to their great joy that a ship of similar dimensions to their own was entering the harbour, and sailing up to the town. She continued thus to advance towards the town, nearly in a north direction, with all her sails set, for nearly half an hour, though the wind was directly against her; until at length, when arriving very near the spectators who had assembled to see her, the tops of her masts seemed to be blown off, then other portions of her masts and rigging, and in a few minutes the whole ship had disappeared!

The feelings likely to be produced in the minds of the people by such an occurrence, at such a time, and under such circumstances, may easily be imagined. Nor is it wonderful they should conclude that a kind Providence had taken this method "for the quieting of their afflicted spirits," to intimate to them the fate which had befallen their beloved ship, and lamented fellow-citizens.

The ship seen by them was, no doubt, the image of a ship, formed in the air in the manner explained above, which was sailing by at the time, but so distant as to be beyond the horizon. Her disappearance in so singular a manner was probably occasioned by the breaking up of the strata of air, which, by its unusual refraction, had produced the phenomenon.

406. In Egypt and other countries, a different kind of mirage is often seen. The traveller passing over the burning sands, on approaching a village, sees, as he supposes, a vast lake of water spread out before him, from the surface of which all objects beyond are beautifully reflected, precisely as from the surface of tranquil water. This is occasioned by the strata of air at the surface becoming suddenly heated, by its proximity to the heated sand, and rendered less dense than the air above it; the rays of light from distant objects and from the sky are then bent upward, and brought to the eye just as if reflected from the plane surface of a smooth lake. As the traveller ap-

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Quest. 405. What were the circumstances that occurred at New Haven in June, 1647? How are these occurrences accounted for? 406. What is said of the occurrence of mirage in Egypt? How are they explained? Why

proaches the village, the supposed lake of course vanishes, and nothing appears but the same burning sands he has for hours perhaps been passing over.

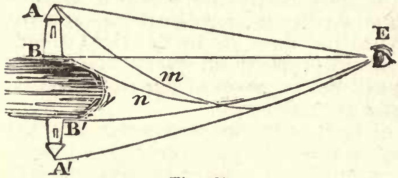

Fig. 195.

Let A B, figure 195, be an object seen at a distance by the rays, AE, and BE; other rays, as A m and B n, passing downward through heated, and therefore less dense strata of air, are refracted upward to the eye at E, causing an inverted image of the object to appear at A′ B′.

407. That the above is the true explanation of these singular phenomena may be shown by direct experiment. Let a square phial be partly filled with a very dense and perfectly clear solution of sugar, and above it introduce carefully an equal quantity of pure water. The solution of sugar, being more dense than the water, will remain at the bottom; but the two will mix more or less at the surface of contact, and form a stratum, the density of which will diminish upward. If, now, a small object, as a card with a word written upon it, be held on the further side of the phial, the word will appear in its natural position when viewed through the water or the sugar solution, but when seen through the mixed liquid, it will be inverted, and out of its true place.

The intelligent student will observe that these phenomena of mirage are only extreme cases of atmospheric refraction of the same kind as those described above (§ 364), and are therefore very properly termed cases of extraordinary or unusual refraction.

POLARIZATION OF LIGHT.—DOUBLE REFRACTION.

408. The polarization of light is a difficult branch of the science of optics, and only a few of its more important principles can be discussed in an elementary work like the present.

Polarization of Light by Reflection.—If a beam of light from the sun be admitted into a dark room through a circular aperture in the window-shutter, and a little fine dust, as powdered starch, or chalk diffused through the air, or even the dense smoke of burning paper, the beam will be seen by the reflection of the light from the floating particles to be everywhere circular, and will appear like a perfectly straight cylindrical rod, drawn across the room. If we hold a piece of paper in the beam, a cir-

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does the lake disappear as the traveller approaches it? 407. May this phenomenon be imitated by an experiment? How is it done? Are these phenomena to be considered as extreme cases of ordinary refraction? 408. When a ray of light from the sun is admitted into a darkened room in which some fine dust or smoke is diffused, what appearance does it present?

cular luminous spot will be produced of the same size or a little larger than the aperture through which the light is admitted.

409. If a piece of window-glass, previously coated on one side with black varnish, be now held in the beam of light, it may be reflected with equal facility in any direction—upward to the ceiling, downward to the floor, or to the right or left. That is, it possesses the same property on every side; for it will be convenient to speak of the beam of light as having a right and left, an upper and an under side.

410. But if the beam of light, after its admission into the chamber, instead of being allowed to pass directly across, is made to fall at the proper angle on a piece of glass painted black on one side, and laid on a table with its unpainted side upward, the beam now reflected from it will be found to have undergone a remarkable change. It may now be reflected upward or downward by another piece of painted glass, as before, but cannot be reflected to the right or left. That is, its right and left sides possess peculiar properties, by reason of which it refuses to be again reflected in these directions, and the light is said to be *polarized.*

411. When, as in this case, the ray of polarized light cannot be reflected in a horizontal direction to the right or left, it is said to be polarized in a vertical plane, or the plane of polarization is said to be vertical. If it could be reflected vertically but not horizontally, the plane of polarization would then be said to be horizontal. When a ray is polarized by reflection, the plane of polarization is always perpendicular to the reflecting surface. The second plate, therefore, is capable of reflecting the polarized ray in its plane of polarization, but will not reflect it in a plane perpendicular to the plane of polarization.

412. It is to be particularly observed that in order to exhibit these phenomena in the best manner, the ray of light must make the proper angle of incidence, which is about 56°, with both of the glass plates. If the angle of incidence at the first plate varies a little from 56°, the ray will not be completely polarized, and a portion of the light will therefore be reflected from the second plate; and if it makes the proper angle with

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Quest. 409. May the beam of light be reflected in every direction by means of a piece of painted glass? Does it possess the same properties on all its sides? 410. If, after the ray enters the room, it is reflected at the proper angle from the surface of a piece of glass laid horizontally upon a table, and an attempt be made to reflect it a second time by a piece of glass, what will be the result? In what directions may it now be reflected? and in what directions does it refuse to be reflected? 411. When is a ray of light said to be polarized in a vertical plane? When is the plane of polarization said to be horizontal? When a ray of light is polarized by reflection, what is the position of the plane of polarization with reference to the reflecting surface? Will the second glass plate reflect the polarized ray in the plane of polarization? 412. What is the angle of complete polarization? What will be the effect if the ray does not make exactly the proper angle with either the first or second plate?

the first plate, but not with the second, the same result will be obtained.

413. As it is often inconvenient to obtain a direct ray from the sun in a darkened room, a lighted candle may be used for the experiment with good success.

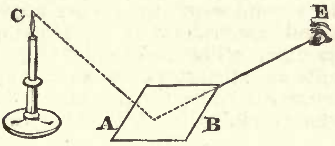

Fig. 196.

Let A B, figure 196, be a plate of painted glass placed upon a table, and C, a lighted candle at such a distance from it that the light from the blaze shall make with the centre of the plate the proper angle of incidence 56°. Then let a person station himself with his eye at E, so as to see the image of the candle in the plate, A B; and taking a second plate of painted glass in his right hand, let him hold it against the right side of his face so as to see in it the image of the candle reflected from the first plate; and then, carefully keeping his eye upon it, let him turn his whole body gradually to the right. The plate upon the table and the image of the candle in it will seem also to be carried round as he turns; and if he has been successful in causing the light to make the proper angle with the plates, the image will become more and more faint as he turns, until at length it will nearly disappear. By turning himself back again, the image is made gradually to resume its former brilliancy. There will be a little difficulty at first in performing the experiment, but a few persevering attempts will insure success. It will be found that the image of the candle is faintest when the second plate is in a particular position, and becomes brighter whenever this position is changed in any direction.

If painted glass cannot be conveniently obtained, the experiment will succeed very well if only a piece of black cloth, or a black glove, is laid under the first plate of glass, and another piece is held against the back of the second plate. The results of the experiment will also be more satisfactory if several plates of glass are placed upon each other on the table, the under side of the lower one only being painted. The light reflected to the second plate will be much stronger than if a single plate only is used.

414. Another method of performing the experiment is to place the first plate of glass, A B, upon a table standing in front of a window, so that the reflection of the sky may be seen in it at the proper angle; and then taking a second plate, and hold-

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Quest. 413. How may the experiment of polarizing light be performed by means of a candle? Is it essential to have the pieces of glass painted? Will it be advantageous to use several polarizing plates instead of a single one? 414. How may the experiment be performed by means of light from the sky?

ing it, as described above, so as to see in it the reflection of the sky from the first plate, and turning the body as before. As the body is turned, the white light, at first reflected, gradually vanishes, until at length the plate appears nearly black. The sky-light being polarized by its reflection from the first plate, refuses to be reflected from the second when the proper angle is attained, and becomes less and less brilliant as this angle is approximated. In rough experiments like these, therefore, it is not to be expected that results as satisfactory can be obtained as by the use of apparatus constructed for the purpose, with all the necessary adjustments for obtaining the proper angles.

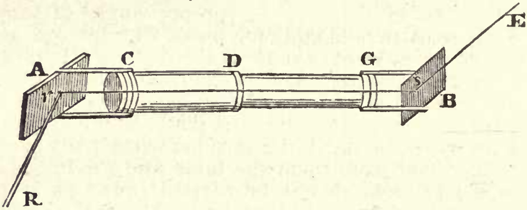

Fig. 197.

415. The principal parts of a piece of apparatus, called a *polariscope*, used for polarizing light by reflection, is represented in figure 197. C D is a tube about 2 inches in diameter, usually made of brass, and D G a smaller tube of the same material, made so as to slide in the former. A and B are plates of painted glass fixed to their supports in such a manner that the ray *r s* shall make the proper angle of 56° with both of them. Let the apparatus be now placed on a proper support near a window, so that a ray of light, R *r*, from the sky, may fall upon it, and be reflected through the tube to the second plate, B. Since the tube, D G, can be made to turn in the larger tube, C D, which is supposed to be fixed, there will be no difficulty, as there was before, in putting the plates in the proper position with reference to each other.

Let a ray of light, R *r*, from the sky, or from a lighted candle, be received upon the plate, A, so as to be reflected at the proper angle through the tubes to the plate, B, and let the tube, D G, be gradually turned round in the larger tube, C D, the eye being all the time kept at E. When the plates, A and B, are in the position indicated in the figure; that is, when the plane, *r s* E, is perpendicular to the plane, R *r s*— the plane of polarization (§ 411)—but a very faint light will be perceived; but as the tube, C D, is turned in either direction, the light will increase, and will be brightest when it has made a quarter of a revolu-

Quest. 415. What are some of the principal parts of the apparatus for polarizing light represented in figure 197?

tion. The planes, R r s, and r s E, it will be perceived, will then correspond, in whichever direction the tube, D G, has been turned. But if the tube is turned still further, the light again becomes fainter, and nearly disappears, when another quarter of a revolution has been made, bringing the two planes, R r s, and r s E, again perpendicular to each other. By turning through another half of a revolution, the same changes will be again observed as have just been produced.

416. In all these experiments, the action of the first or polarizing plate seems to be to divide, or decompose, the light into two parts, one of which is reflected from its surface to the second plate, while the other passes through it and is absorbed by the black paint or cloth on the other side.

417. Though we have thus far made use of the angle of 56° as the proper angle of incidence for polarizing light by reflection from glass, it should be remarked that the more correct angle is 56¾ degrees. Light is also polarized by reflection from the surfaces of other bodies; but, to undergo this change, it must be incident upon them at different angles. Thus, for water, the proper polarizing angle is a little more than 53°, for sulphur, nearly 64°, and for the diamond, 68°. When light is incident upon these substances at angles varying a little from the above, it is still polarized, but the polarization is not complete.

418. *Polarization of Light by Double Refraction.*—Long before anything was known of the polarization of light, it was discovered that certain transparent substances possess the property of dividing a ray of light transmitted through them into two parts, and causing small objects seen through them to appear double. This property belongs more particularly to crystallized bodies, as Iceland spar (crystallized carbonate of lime), quartz, &c.; but is also possessed by other bodies, as glass, in certain circumstances.

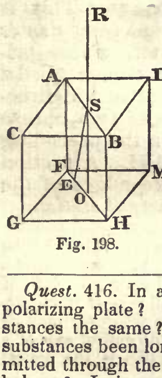

Fig. 198.

Let A C B D F G H M, figure 198, be a crystal of Iceland spar, and R S a ray of light falling perpendicularly upon it at S; as it passes through the crystal it will be divided into two parts, S O, and S E, the part S O passing directly through it, as it would through glass or water without refraction (§ 360); but the other, S E, being bent considerably out of the original direction. The ray, S O, is called the *ordinary*, and S E, the *extraordinary* ray.

419. If a piece of white paper, with a dot upon it at O, is laid under the crystal, there

Quest. 416. In all these experiments, what is the action of the first or polarizing plate? 417. Is the angle of complete polarization for all substances the same? 418. What peculiar property have certain transparent substances been long known to possess with regard to a ray of light transmitted through them? To what bodies does this property more particularly belong? Is it possessed by other bodies also to some extent? What are the two rays called? 419. If a crystal of Iceland spar is laid upon a piece

will appear to be two dots, one at O and the other at E. If the crystal is gradually turned round on the paper, the dot, E, will appear to revolve around O, keeping always on the same side of it, with reference to the axis of the crystal. A line drawn upon the paper in the direction G M, when observed through the crystal, will also appear double, a second line being seen passing through E, parallel to the first; but, if the crystal is turned round, this second line appears to approach the first, and at length perfectly coincides with it when the crystal has made a quarter of a revolution. If the crystal is turned still further, the line makes its appearance on the other side of O, and attains its greatest distance from O when the crystal has made just half a revolution. When the crystal has made three quarters of a revolution, the lines will again coincide; and if it is turned still further, the second line again makes its appearance on the same side of O as at first, both lines taking the same position they had at the beginning when the crystal has made a full revolution.

420. We have, in the above experiments, supposed the ray of light to be perpendicular to the crystal, and we find the ordinary ray passes directly through without refraction, while the other, the extraordinary ray, is refracted. If the ray of common light is made to strike the crystal obliquely, it will still be separated into two parts, as before, and the ordinary ray will be refracted according to the law of refraction already described (§ 360), but the extraordinary will deviate entirely from it.

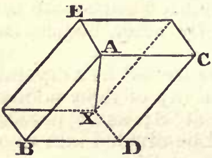

Fig. 199.

421. In every body capable of double refraction, there is at least one direction through which a ray of light will pass without suffering this change. This is called its *optical axis*, or *axis of double refraction.* In Iceland spar, whose primary form is a rhomb (sometimes called a rhombohedron), this axis is in the direction of a line which joins its two obtuse solid angles, &c., A X, figure 199. So this axis in the preceding figure would be a line drawn in the direction A H. A section made through the optical axis and two opposite edges of the crystal, as A B F H, figure 198, is called its *principal section.*

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of white paper marked with a dot, what will be the effect? What will be the effect if the crystal is turned round? What will be the result when a line is drawn upon the paper and the crystal turned round upon it? 420. If the ray of light is incident upon the crystal obliquely, will double refraction still take place? 421. Does double refraction take place whatever may be the direction of the ray through it? What is meant by the *optical axis* of a crystal? In the crystals of Iceland spar, in what direction is the optical axis? What is the *principal section*?

422. The crystals of different substances exhibit this remarkable difference in their action upon light, that in some the extraordinary ray S E, figure 198, is bent *from* the axis, while in others it is bent *towards* it. In crystals of Iceland spar this ray is bent from the axis A H; that is, it deviates more from being parallel with the axis than the ordinary ray, S O. In crystals of some other substances, as just intimated, the extraordinary ray, S E, will be refracted *towards* the axis, or will be found on the other side of S O, towards H, and it will then, it is evident, be more nearly parallel with the axis than the ordinary ray. When the extraordinary ray is refracted from the axis, the crystal is said to have a *negative* axis; but, when it is refracted towards the axis, it is said to have a *positive* axis.

In crystals of many substances, there are two or even a greater number of axes of double refraction; but the subject then becomes too complex to be here discussed.

423. A ray of light, then, on passing through a double refracting substance, is separated into two distinct parts, which take entirely different courses through it. But the separation of the rays is not the only effect produced by the doubly refracting substance. If the rays, after separation, are examined, they are both found to be polarized with their planes of polarization at right angles to each other; that is, if the two rays, which we will suppose to be horizontal, are separately made to fall upon a piece of painted glass at the proper angle of incidence (56°), they will both exhibit the same peculiarities as a ray polarized by reflection (§ 410); but, if one of them may be capable of reflection upward and downward, while it refuses to be reflected to the right or left, then the other will allow itself to be reflected to the right or left, while it refuses to be reflected vertically. The ordinary ray is always polarized in a plane corresponding to the principal section, and the extraordinary ray in a plane at right angles to this. Consequently, if we suppose the experiment made by placing a doubly refracting crystal, with its principal section vertical, in a small aperture made for the purpose in the window-shutter of a darkened room, through which a direct ray from the sun may be received, then the ordinary ray will not be reflected horizontally by a glass plate, nor the extraordinary ray vertically, while the former will allow itself to be reflected vertically, and the extraordinary ray horizontally.

Quest. 422. What difference is there in the crystals of different substances in reference to the direction in which the extraordinary ray is refracted? Is there ever more than one axis of double refraction? 423. If the two rays are examined after passing the crystal, in what respects will they be found to differ from each other as it regards their planes of polarization? If a ray of light is received through a crystal placed in a hole in the window-shutter with its principal section vertical, in what directions may the ordinary ray be reflected? and in what directions the extraordinary ray?

424. We may, therefore, consider a ray of common light as made up of two separate rays which are polarized in opposite planes; that is, in planes which are at right angles to each other. The double refraction of light is, therefore, a species of decomposition (§ 379), by which it is separated into two distinct rays, which are not indeed of different colours, as in the case of its decomposition by means of the prism, but which, nevertheless, as we have seen, are entirely different in some of their properties.

425. When light is polarized by reflection, as above described (§ 410), the same decomposition takes place, though the results are a little different. When light is polarized by double refraction, both rays, after separation, pass onward in their course, though in directions a little different; but when it is polarized by reflection, one only is reflected to the eye, while the other, as before remarked, passes through the plate of glass, and is absorbed by the black paint or other substance on the opposite side (§ 416). This is proved by using a plate of glass unpainted, and examining the ray which is transmitted by it. This ray is thus found to be polarized equally with the reflected ray, but in a plane at right angles to the plane of polarization of the reflected ray.

426. *Polarization of Light by Absorption.* — Polarized light may also be obtained by simply transmitting a ray of common light through thin plates of certain substances, as brown tourmaline, and agate, when cut and polished in the proper directions. In this case, the ray of common light is decomposed into two rays polarized in opposite planes, as before, and one of them is transmitted while the other is absorbed or stifled by the polarizing substance.

Tourmaline crystals are usually in the form of six-sided prisms, the optical axis of which corresponds with the axis of the crystal; and pieces prepared for polarizing light are thin slips cut parallel to the axis, and polished. If we look at the sky through such a piece, a distinct yellow light is seen, which is scarcely diminished by placing a second piece of tourmaline on the first, provided the two are parallel with their lengths in the same direction. But if now one of the pieces be slowly turned round upon the other, the quantity of light transmitted to the eye will gradually diminish, and will entirely vanish

Quest. 424. Of what may we consider the common ray of light to consist? Is the double refraction of light a species of decomposition? 425. Is the same decomposition produced when light is polarized by reflection? When light is polarized by reflection, what becomes of the part that is not reflected? How is this proved? 426. What is the effect when a ray of light is transmitted through plates of tourmaline or agate cut in the proper direction? How are the two rays in this case separated from each other? If we look at the sky through one of these plates of tourmaline, what will be the effect? If two plates are used, and one is made to turn round upon the other as the

when the crystals lie across each other, or their lengths are at right angles. If it be turned further, the light again appears.

By the first piece of crystal, in this experiment, the ordinary or common ray of light is separated into two rays polarized in planes at right angles to each other, one of which is absorbed by the substance, and the other transmitted, its plane of polarization being at right angles to the axis of the crystal. When, therefore, a second plate of tourmaline is presented, having its axis in a plane at right angles to the axis of the first, the ray refuses to pass.

427. *Polarization of Light by Successive Reflections.* — Another method still of polarizing light is by numerous successive reflections from the surface of glass or other reflecting substance, at an angle of incidence varying more or less from the angle of complete polarization. Thus, though the angle of complete polarization for glass is, as above stated, 56°, yet by six successive reflections at an angle of 70°, a ray may be as completely polarized as by a single reflection at an angle of 56°. So, by numerous reflections at other angles greater or less than 56°, the same effects are produced.

428. A ray of common light, then, being considered as composed of two rays, polarized in opposite planes, the several methods of separating these rays, and obtaining them in a state of separation, are the four following, viz:

1. By causing the ray to be incident upon a proper reflecting surface, as that of glass or water, at its angle of complete polarization (§ 410), by which means the two rays of which it is naturally composed are separated, one being reflected from the surface polarized in the plane of reflection, and the other passing through the glass (§ 416), and emerging polarized in a plane perpendicular to the first.

2. By transmission through a doubly refracting crystal, by which the rays are separated and made to diverge a little from each other.

3. By transmission through some substance, as a thin plate of brown tourmaline or agate, by which the rays are separated as before, and one of them absorbed or stifled by the polarizing body, the other passing through.

4. By a number of successive reflections from the surface of some transparent substance at other angles than that of complete polarization; by which means it is supposed the planes of polarization are turned round so as to coincide with each other.

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eye looks through them to the clouds, what will be the result? How is this explained? 427. May light be polarized by numerous successive reflections at any angle of incidence? 428. What four methods of polarizing light have we?

429. *Colours produced by Polarization.*—By means of polarized light, the most splendid colours may be produced, of singular brilliancy. To exhibit these colours to the best advantage, a nicely constructed apparatus is required, like that represented in figure 197, with the addition of a ring between the end of the tube, G, and the plate, B, on which a thin plate of selenite,* or mica, may be placed, in such a manner that the ray reflected from the plate, A, may pass perpendicularly through it.

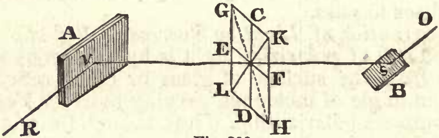

Fig. 200.

In order to exhibit the position of the glass plates and the plate of selenite in the plainest manner, let us suppose the tube CG, figure 197, removed, the glass plates, A and B, remaining in the same position as before, as represented in figure 200, and let GKHL be the plate of selenite or mica. This should be not more than $\frac{1}{20}$th of an inch in thickness, and should be held so that the ray *r s* shall pass perpendicularly through it. Let us suppose, also, that the plate of selenite is held, as represented in the figure, so that the line CD shall be in the plane *r s* O; if the eye be now placed at O, nothing but the dark surface of the glass will be seen (§ 413), the plates A and B being in the position in which the light that is reflected polarized from the first plate A, refuses to be reflected from the second plate B. But if the plate of selenite be now slowly turned round, as if on the line *r s* as an axis, it will appear to the eye, placed at C, to be covered with the most beautiful tints, which become more and more brilliant until the line GH comes to the position now occupied by CD. If it is turned still further, the brilliancy of the colours will then diminish until the line EF is brought to the present position of CD, when they will entirely vanish, and only the dark surface of the glass will be seen, as at the commencement. It will be observed that the plate of selenite has now made just a quarter of a revolution; if it is turned still further, the same appearances will present themselves as before, the colours alternately appearing and disappearing at each quarter of a revolution.

Quest. 429. What is said of the colours which may be produced by polarized light? What substance is used between the reflecting plates of the polariscope in producing these colours? What will be the effect of turning the plate of selenite round as described?

* Selenite is merely crystallized sulphate of lime or plaster of Paris. It is usually in thin plates which are easily separated, and are very transparent. Mica is the well-known substance used in the windows of stoves. It is sometimes, though very improperly, called isinglass.

430. It is found that the particular colours that are produced depend upon the thickness of the plate of selenite; if this is uniform, the colour will be uniform throughout; but, if it is thicker at some places than at others, as will always be the case in a piece split off from a mass, each of the parts of different thicknesses will have a tint of its own. If the plate of selenite is inclined a little to the ray *r s*, a different tint of every part will be produced, as the ray will then pass through a greater thickness of it.

431. Let us now suppose we have a plate of selenite of such a thickness as to give a uniform red colour, and let us suppose it fixed in the position in which the colour is brightest; this will be when the line G H is in the position occupied by C D in the figure (§ 429). Let the plate B be now turned round in such a manner that it shall constantly make the same angle with the ray *r s;* when it begins to move, the brilliancy of the colour will instantly begin to diminish, and will entirely disappear when the plate B has made $\frac{1}{8}$th of a revolution, or has been turned through 45°. If it is turned still further, the plate of selenite, as seen by reflection from B, will be coloured green, which attains its greatest brilliancy when the plate B has made another eighth of a revolution, or has been turned a quarter round from its first position. If the plate B is turned still another eighth of a revolution, the green gradually becomes fainter and fainter, and at length vanishes; beyond this the red again appears, and attains its greatest brilliancy when the plate B has been turned half round from its position at the beginning of the experiment. By turning through another half of a revolution the same changes are produced as have just been described, and in the same order.

432. These two colours, red and green, are said to be complementary to each other, because, when united, they produce white light. The solar spectrum contains the three rays, red, yellow, and blue (§ 297), which, united, produce white; but the yellow and blue united produce green; therefore the red and green united must produce white. So the orange and the blue united produce white, and are therefore complementary to each other. In the above experiment the colours which appear as the plate, B, revolves always sustain this relation to each other; if one is red, the other will be green; if one is

Quest. 430. Upon what will the particular colours produced depend? What will be the effect if the plate of selenite is of different thicknesses? What will be the effect if the plate is inclined a little to the direction of the polarized ray? 431. If the plate of selenite be of such a thickness, and in the proper position to produce a brilliant red, what will be the effect if the second plate, B, is carefully turned round in the manner described? How often in each revolution will the red and the green each appear and disappear? 432. Why are the colours red and green said to be complementary to each other? Will the two colours which appear by the revolution of the plate, B, always be complementary to each other?

orange, the other will be blue; the two always being such as, when united, to produce white.

433. If the student finds any difficulty in understanding the true motion which is to be given to the plate, B, let him refer again to figure 197, in which the plates are represented as connected by a tube composed of two parts, C D and D G, the latter of which is capable of turning in the former. The motion supposed to be given to the plate, B, in the above description, will be produced simply by turning the part, G, to which the plate, B, is attached, in the part, D C, which is supposed to be fixed. The plate, B, while the tube is turned, will then constantly make the same angle (56°) with the polarized ray, *r s*.

434. Some of the important results of the above experiment may be determined merely by the use of a couple of pieces of painted window-glass, as described above (§ 412), and a small plate of selenite, which may be split from almost any crystallized specimen of sulphate of lime. A plate of mica, of the proper thickness, answers the same purpose. Let a piece of painted glass be placed upon a table near a window, so that while skylight shall be reflected from it to the eye of a person standing a little distance from it, at the proper angle of incidence (56°) as nearly as possible; and then, as before (§ 415), let him hold a second piece of painted glass in his right hand, so as to see in it the light reflected from the first plate. By turning gradually to the right, the brilliancy of the light will diminish, and when the proper position of the plates, with reference to each other, is obtained, will nearly vanish, the surface of the first plate on the table appearing black, as seen by reflection from the second plate. If, now, the plate of selenite or mica, held in the left hand, is interposed between the glass plates, so that the light reflected from the first shall pass perpendicularly through it on its passage to the second plate, it will appear beautifully coloured, as above described, the particular tints that are produced depending upon the various circumstances above enumerated (§ 431). It will not be possible, in this rough manner, to cause any colours, as the red and green (§ 429), to appear and disappear regularly by turning the glass plate held in the hand; but it will not be difficult, by turning the plate of selenite carefully one way and the other, to find that, when held in two positions, with reference to the plane of reflection of the second glass, no colour will be produced, but only the dark surface of the first plate will be seen through the selenite; in all other positions of it, the colours will appear.

Quest. 433. How may some of the important results above detailed be determined merely by the use of a couple of pieces of painted window-glass and a plate of selenite or mica? Will it be possible, in this rough manner, to cause the complementary colours, as red and green, to appear regularly and disappear by turning round the plate, B?

435. The young student, in attempting to perform this experiment, will find the greatest difficulty in getting the proper position for the two glass plates; but he may always know when the object is accomplished, for then the surface of the first plate (the one placed upon the table) will appear black when seen by reflection from the second plate. The difficulty in a particular case may be occasioned by the light not being reflected from the first plate at the proper angle of incidence (56°), or by the second plate not being held in the proper position with respect to the first. Perfect success can be obtained only after a number of trials. If the first trial is not satisfactory, and it is suspected that the light is not received on the second plate at the proper angle of reflection from the first plate, the person should advance a little nearer to the table, or step back a little farther from it, as he may judge necessary, by which the angle of reflection will be changed. But care should always be taken that the white light of the sky is reflected to the eye, which will not be the case, of course, if the shade of a tree, or an adjacent building, or other object is seen upon the glass plate. To find the proper position of the second glass plate scarcely any directions can be given in addition to what has been already said (§ 414); but it is to be observed that very brilliant colours will be produced, even if the exact angles for producing complete polarization are not obtained. The colours, however, appear much the most beautiful when every part is in its proper position.

436. If, instead of the plate of selenite or mica, in the above experiments, a crystal of Iceland spar be used, the ray passing through it in the direction of its optical axis, brilliant colours will be produced, as before, but they will be arranged in concentric circles. To prepare a crystal for this purpose, planes should be cut and polished at the extremities of the axis, and perpendicular to it, as represented in figure 201.

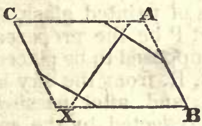

Fig. 201.

A B X C is the perfect crystal, and the line A X its optical axis, in the direction of which light will pass without undergoing double refraction (§ 418). The parts at the extremities of the axis, A X, represented by dotted lines, are to be ground down and polished; and a ray of light incident upon one of these faces perpendicularly will then pass directly through parallel with the axis.

437. Having the glass plates in the proper position for producing complete polarization, as described above—that is, having them so situated that the first plate appears black when seen by reflection from the first—let the prepared crystal of Iceland spar be interposed by the left hand between them, in the same manner as the plate of selenite (§ 434), and it will be seen covered with a beautiful system of coloured rings, inter-

Quest. 436. If, instead of the plate of selenite or mica, as described, a crystal of Iceland spar be used, through which the ray is made to pass in the direction of its optical axis, what will be the result? 437. If, when the two plates are so situated as to produce complete polarization, the prepared crystal of selenite be introduced between them, what will be the appearance?

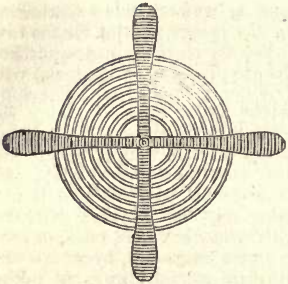

Fig. 202.

sected by a black cross, as represented in figure 202. These rings will be best seen when the plates are held as near together as possible, with the eye very near the second plate.

In this experiment no change is produced by turning round the Iceland spar, but if the second glass plate is made to revolve gradually, keeping it at the proper angle to the polarized ray, the rings will be found to vary in intensity; and when a quarter of a revolution has been made, an entirely new system of rings will be seen intersected by a luminous cross, as shown in figure 203.

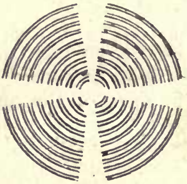

Fig. 203.

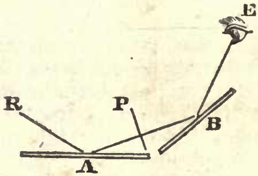

Fig. 204.

438. To form this last system of rings, with the luminous cross, in a familiar way, let the two plates of painted glass, A and B, be placed as in figure 204, and let P be the prepared crystal of Iceland spar. The plates being supposed to be placed on a table before a window, a ray of light, R, from the sky is polarized by reflection from the plate A, and, after passing through the crystal of Iceland spar, P, is reflected by the second plate, B, to the eye at E, producing the system of coloured rings just described.

The system of rings represented in figure 202, with the dark cross, may also be formed simply by turning one of the plates a quarter round, so that their planes of reflection shall be at right angles to each other, and holding the prepared crystal of Iceland spar as before.

439. These experiments are more easily performed by using thin plates of tourmaline (§ 423), properly prepared, instead of the glass plates, but it is difficult to procure them. The same might be said of the experiments in polarizing light, already described.

Should the plates be held near each other in performing this experiment? What will be the effect if the plate B is gradually turned round? 437. May the same results be obtained by using thin plates of tourmaline instead of the

Crystals of substances which possess two axes of double refraction, when properly cut and polished, usually produce two systems of coloured rings, which are variously situated with respect to each other, according to their structure and the position of their axes.

CHAPTER VI.

VISION.

440. The explanation of the structure of the eye, and the laws of vision, forms a most important and interesting branch of the science of optics. In the whole range of natural science there is not to be found a more beautiful and impressive instance of the wonderful skill and benevolence of the Divine Architect than in the formation of the eye, and its adaptation to the purposes for which it is designed.

441. The human eye, except a small portion which projects in front, is of a very perfect spherical form, and is situated in a deep cavity in the bones of the head, which is called its *orbit*. It is thus protected from mechanical injuries, to which it would otherwise be constantly liable. As it is situated, only a very small, or a pointed object, can reach it; and but a small part of it is exposed to injury even from such objects. Hence it is that so delicate an organ is preserved in perfect order, except the slight decay of age, during a long course of years, in the midst of the numerous accidents to which every one, during life, is exposed.

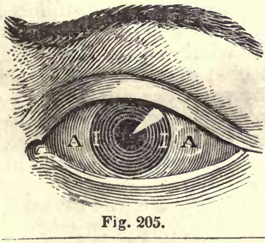

Fig. 205.

442. The different parts of the eye which we shall notice are the thin coats, or membranes, which are called the *sclerotic* coat (sometimes, also, called the *sclerotica*), the *choroid* coat, and the *retina;* the two humours, the *aqueous* and the *vitreous;* the *crystalline lens* and the *iris.*

Figure 205 is a front view of the eye, and some of the adjacent parts. A A is a part of the *sclerotic coat*,

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reflecting plates of glass? Do crystals possessing two optical axes produce two systems of coloured rings? 440. What is said of the skill and benevolence of the Divine Architect, as indicated in the formation of the eye, and its adaptation to the purposes designed? 441. What is the form of the human eye? Where is it situated? How is it protected from mechanical injury? 442. What are some of the parts of the eye to be noticed? What is the

usually called the white of the eye, being always of a beautiful white colour; I I is the iris, so called from the circumstance of its presenting so many different shades of colour, being in some persons black, in others blue or gray. In the centre of the iris is a small circular opening, called the *pupil*, varying from one to two or three tenths of an inch in diameter, according to circumstances to be hereafter noticed. Through this small aperture all the light enters by which vision is produced.

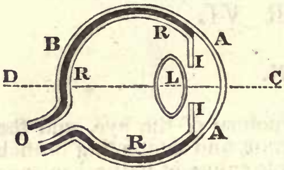

Fig. 206.

443. Figure 206 is a section of the left eye through the centre of the pupil, parallel to the opening of the eye-lids, the lower side being supposed next to the nose. A B B A is the sclerotica; it is a strong and tough membrane, perfectly white, and to it are attached the several muscles by which the eye is moved in its socket, so as to enable the person to see in different directions without turning the head. A A is the *cornea*, which is a perfectly transparent membrane covering the front of the eye, and connecting with the sclerotic coat all around, as at A A. It receives its name from its resemblance to transparent horn (Latin *cornu*). Next inside of the sclerotica is the *choroid* coat, indicated by a darker line; it is a delicate membrane, extending from the optic nerve, O, in the back part of the eye, to the iris, I I, in front, with which it is connected. On its inside it is covered with a perfectly black substance, called the *pigmentum nigrum*, by which any reflection from the internal parts of the eye is prevented. It also serves to absorb any light which may find its way through the sclerotic coat, the two producing a perfectly darkened chamber within, into which light is admitted only through the pupil, as through a window. The third coat is the *retina*, R R R, which is merely an expansion of the optic nerve, O, and lines the whole of the back part of the cavity of the eye. Upon this coat a perfect image is always formed of every object seen by the eye; and the production of this image is always accompanied by the sensation of sight, provided the optic nerve, which connects the eye with the brain, is in a healthy state. This nerve enters the eye in

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common name of the *sclerotic coat?* Where is the iris situated? What is the pupil? 443. What is represented in figure 206? What is the sclerotic coat composed of? Where is the *cornea?* From what does it derive its name? Where is the choroid coat? With what is it covered on the inside? What purpose is served by this black substance? Where is the retina situated? What is it? What is always formed on the retina when perfect vision takes place? Is the formation of the image upon the retina always attended by the sensation of sight when the optic nerve is in a healthy state?

the back part, about one-tenth of an inch from the axis, on the inside, towards the nose.

The crystalline lens, L, is a compact, transparent substance, in the form of a double convex lens, but having one surface more convex than the other; in connection with the iris, I I, it divides the eye into two very unequal parts, called the *anterior* and *posterior chambers.* The anterior or frontal chamber is filled with a limpid liquor, like water, called the *aqueous humour;* and the dense *vitreous humour* fills the posterior chamber.

An imaginary straight line, C D, drawn perpendicularly through the pupil, is called the *axis* of the eye. The distance on this line from the cornea to the back part of the eye is generally a little less than an inch.

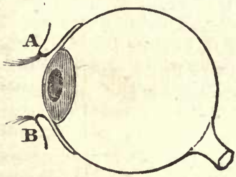

Fig. 207.

In front of the whole eye is the *conjunctiva*, which is a transparent membrane designed to protect the eye from the entrance of dust and other matter between the eye and its socket. It consists merely of the common skin of the eye-lids, A and B, figure 207, above and below the eye, which, after passing the edges of the lids, folds in a little distance, and is reflected over the surface of the cornea. Foreign matter, therefore, which enters around the eye can never find its way farther than the fold of this membrane extends; which, however, we know often causes great pain.

444. Let us now inquire concerning the effect of these different parts of the eye in producing vision. It is to be recollected that every point of a visible object (§ 336) is constantly emitting rays of light in every direction; and to see an object is to see the points of which its surface, presented towards the eye, is made up, arranged in their proper order (§ 351). Of the rays emitted from any point only a small portion can enter the eye, so that the same point may be seen at the same time by many eyes situated in the vicinity of each other, though not by means of the same rays. Let A B C, figure 208, be an object in front of an eye; of the rays emitted from the

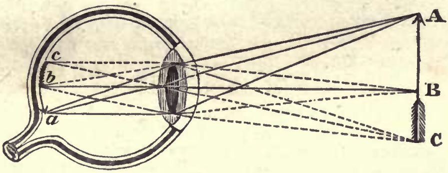

Fig. 208.

Where does the optic nerve enter the eye? What is the form of the crystalline lens? What are meant by the *anterior* and *posterior chambers* of the eye? What humour fills the anterior chamber? What fills the posterior chamber? What is the *axis* of the eye? What is the conjunctiva? What does it consist of? 444. What is it to see an object? Will all the rays from

point A, a small portion will enter the pupil, but all the rays in the vicinity which come in contact with the opake parts of the eye will be reflected or absorbed. The rays that enter the eye will form a cone, the base of which will be at the pupil, and the apex at the point from which they are emitted. When these rays enter the cornea, which is a more dense medium than the air, they will be made to converge; and this effect will be still further increased by their passing through the crystalline lens, so that they will be brought to a focus on the retina at *a*, producing there an image of the point A of the object from which they were first emitted. From every other point of the object, as B and C, cones of rays will proceed in like manner, producing at *b* and *c*, on the retina, corresponding images of these points. The result of the whole will, therefore, be the production, on the retina in the back part of the eye, of an inverted image, *a b c*, of the object A B C (§ 374).

Both the aqueous and vitreous humours have some effect in bringing the rays to a focus on the retina for the production of the image, but the crystalline lens is the most important. The form of this, as we have seen, is double convex, the convexity being greatest on the side next to the vitreous humour, while the aqueous humour has the form of a meniscus, with its convex side presented to the rays, and the vitreous that of a convex or concave lens (§ 369).

445. We know, merely by an examination of the different parts of the eye, that when an object is placed in front of it, an image of it will be formed on the retina in the back part; but the same thing can be shown by direct experiment. For this purpose the eye of an ox or other animal which has been recently killed is taken, and the two outer coats carefully removed from the back part, so as to expose the semi-transparent retina. If, when thus prepared, it is held before a window, or other bright object, the inverted image, perfectly distinct, will be seen formed upon the retina. As this membrane is semi-

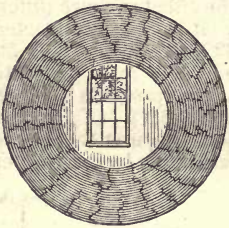

Fig. 209.

each point of an object enter the eye? What will the rays that enter the eye from any point form? What effect is produced upon this cone of rays from any point where they enter the cornea? What will be the effect when they pass the crystalline lens? Where will the image of the point be formed? Will similar images of other points be formed? What will the result of the whole be? Do the vitreous and aqueous humours produce any effect? On which side of the crystalline lens is the greatest convexity? What is the form of the aqueous humour? Of the vitreous humour? 445. How may the eye of an ox or other animal be prepared, so as to exhibit the formation of the image upon the retina of an object in front of it? What is shown in figure 209?

transparent, the image formed upon it is seen through it. Figure 209 represents an eye of an ox prepared in this manner, and held before a window, the inverted image of which is seen in the back part.

446. As the eye, though small, is capable of seeing distinctly, at a single view, the various objects of an extensive landscape, it is evident the images must be painted on the retina with wonderful minuteness. It has been calculated that the image of a portion of the castle of Edinburgh, 500 feet long and 90 feet in height, when seen at a certain distance, does not occupy on the retina more than the twelve hundred thousandth part of an inch, and yet its different parts will be distinctly visible. When a page of a large book is held before the eye, not only is each word and letter distinctly visible, but even the minute defects of the letters; and yet the image of the whole upon the retina will not cover a space so large as the finger-nail! It is not necessary to remark that no painter, however skilful with the pencil, can execute a picture like this.

447. It is well known that the eye is capable of viewing objects distinctly at greatly different distances within certain limits. The least distance of distinct vision for most persons is about 5 inches, but all can see much farther than this. But, in order that a distinct image of objects at different distances may be produced, it is absolutely necessary that the parts of the eye should undergo some change. If the parts of the eye were incapable of change, a distinct image would be formed on the retina only when objects were at a particular distance, but would be confused if the objects were brought nearer or carried farther off. To be satisfied of this, let a person hold a common burning-glass a few feet from a candle, in a dark room, as described above (§ 375), and at a certain distance on the opposite side of the glass, which can easily be found by trial, an inverted image of the candle will be formed on a sheet of paper or other substance held up as a screen to receive it. If the candle be now removed a little farther from the glass, the image at once becomes indistinct, but is again perfectly formed if the screen is brought a little nearer; so if the candle is placed nearer to the glass than when in its first position, the image again becomes indistinct, a perfect image being produced only when the candle and paper are at certain relative distances from the glass.

Quest. 446. What is said of the minuteness with which images of objects must be painted upon the retina? What illustration of this is given in the instance of a person viewing a portion of the castle of Edinburgh at a certain distance? What is said of the space occupied by the image of the page of a book at which a person is looking. 447. Is the eye capable of seeing objects distinctly at different distances from it? What is the least distance of distinct vision for most persons? Must some change take place in the parts of the eye when objects are viewed at different distances? If the parts of the eye were incapable of change, what would be the result? By what

It is found that if the parts of the eye remain unchanged, the distance of the image from the crystalline lens, of objects situated only about 5 inches (§ 446) from the eye, will be about $\frac{1}{8}$th of the diameter of the eye more than if the objects are placed at the greatest distance of distinct vision. But as the image, to produce distinct vision, must always be thrown accurately upon the retina, to enable a person to see both near and distant objects, it is evident the parts of the eye must undergo some change; and that this change does take place every one will be satisfied by looking attentively for some seconds at a well-illuminated distant object, and suddenly turning his eye upon the page of a book held in his hand. For a moment, after turning his eye upon the book, the print will appear more or less blurred, until the parts of the eye which have been adjusted for looking at the distant object have time to put themselves in the proper order for seeing those that are near.

448. There are three modes by which the eye may adjust itself for seeing objects at different distances—that is, so as to cause the image to be formed on the retina, though the distance of the object may vary—viz: 1. By a change in the convexity of the cornea and crystalline lens; or, 2. By a change in the distance of the crystalline lens from the retina; or, 3. By both combined. Thus, if the parts of the eye are adjusted for seeing near objects, to enable it to see clearly distant objects, it is necessary only that the cornea and crystalline lens should be a little flattened, to prevent the rays from coming to a focus before reaching the retina; or, that the crystalline lens should be moved forward a little farther from the retina; or, that both of these changes should take place together. Some writers have affirmed, without qualification, that these changes actually take place, but it is believed no sufficient evidence of them has yet been produced; and the mode by which the eye adjusts itself to see objects at different distances cannot be considered as fully determined.

449. When a person steps suddenly from a room perfectly dark into one well lighted, a painful sensation is produced in the eyes, and he is scarcely able to see, because of the excess of light; but in a short time the eye accommodates itself to the light, and the pain ceases. So, when a person goes at once from a well-lighted apartment into a dark room, or into

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simple experiment may a person satisfy himself of this? If an object is only 5 inches from the eye, how much farther from the crystalline lens will the image be formed than if it is situated at the greatest distance of distinct vision? How may a person satisfy himself that the eye actually undergoes a change when he looks from a near to a distant object, or the reverse? 448. What three modes are mentioned by which the eye may adjust itself so as to perceive objects at different distances? Has it been proved that these changes, or any of them, do actually take place? 449. What is the effect upon the eyes when a person steps suddenly from a dark to a well-lighted apartment? What is the effect of going at once from a room bril-

the open air on a dark night, he is at first scarcely able to distinguish a single object, but by degrees he finds his vision become much more distinct. This, it is well ascertained, is occasioned by the contraction and expansion of the iris, by which the diameter of the pupil is changed. When a person views a well-illuminated object, the diameter of the pupil is scarcely $\frac{1}{10}$th of an inch, and but a small pencil of rays is admitted, which, if he steps into a room only partially lighted, will not be sufficient to produce distinct vision; but the iris spontaneously dilates, and a larger pencil of rays is admitted, to enable him to see distinctly. After remaining a while where there is little light the pupil dilates to its utmost size, and if he now suddenly step into a well-lighted room so much light enters the eye as to produce pain, but the gradual contraction of the pupil soon causes it to cease, by diminishing the quantity of light that is admitted. Any one may witness this change in his own eyes by holding a small mirror in his hand, and so managing as to look suddenly from an obscure object to one that is well illuminated, or the reverse. The eyes of children are especially sensitive to light, and by causing a child to look first at the window, when the sun shines, and then at some object in the room, or the reverse, the change in the size of the pupil will be beautifully exhibited.

450. Some persons, it is said, have the power of enlarging or contracting the pupil of the eye at pleasure, but it is believed this is seldom the case, the change of the pupil to accommodate the eye to the quantity of light being entirely spontaneous, and beyond the control of the will.

451. In some animals the pupil of the eye is susceptible of much greater change than in man, so that they can see equally well with him in the day-time, and much better in the night, when objects are but partially illuminated. This is the case with the horse; and it is well known that he will find his way along in a dark night, when it would be absolutely impossible for a man to do it alone. This is also particularly observable in animals of the cat kind, which are adapted for searching for their prey in the night. Some animals, as bats and certain species of owls, cannot see well in the day-time, and therefore seldom appear abroad except at evening, when their vision becomes distinct; this is because their eyes being adapted for seeing clearly only at night, their pupils do not allow of suffi-

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liantly illuminated into one that is dark, or into the open air in a dark night? How are these facts explained? How may a person notice this change in his own eyes? How may it be noticed in the eyes of a child? 450. Have we the power of enlarging or contracting the pupils of our eyes at pleasure? 451. Are the pupils of the eyes of some animals susceptible of greater change in this respect than those of man? Can such animals see better in the night, when objects are but partially illuminated, than man? In what animals is this particularly observable? Why can some animals see better in the twi-

cient contraction to enable them to see in the broad light of day. The pupil of the eye in man is always round, but in some animals, as the horse, it is elongated in a horizontal direction, while in others, as the cat, it is elongated vertically. The eyes of fishes are always destitute of the aqueous humour, which, as they are designed to live in the water, would be useless; and the crystalline lens is spherical. This is rendered necessary by the fact that the rays of light pass from a dense medium, water, into the eye; for, if the crystalline lens was not more convex than in the eyes of land animals, the rays would not be soon enough brought to a focus, so as to form an image upon the retina.

452. It has been seen above (§ 376) that when rays of light which are parallel, or nearly so, are transmitted through a double convex lens of glass, they are not all brought to a focus at the same distance, but those transmitted near the edge come to a focus nearer to the lens than those which pass through near its centre. This is avoided in the eye by the increased density of the crystalline lens near its centre, by which its refractive power in this part is increased. Besides this, the iris serves as a diaphragm, by which the rays too distant from the axis are excluded. The eye, therefore, is destitute of spherical aberration.

453. It has been seen, likewise, (§ 378), that when light is refracted, the primary colours of which it is composed are separated more or less from each other; so that when a pencil of rays is transmitted through a double convex lens, the image formed will usually appear coloured. But no such effect is produced by the eye, which sees all objects of their natural colour. In the small pencil of light admitted into the eye, only a slight dispersion of the colours can take place, and this, it is supposed, is corrected by the different dispersive powers (§ 386) of the different parts of the eye.

By a particular experiment the colours of the spectrum may be seen, the light being decomposed by the eye. Let a person hold some opake object with a straight edge, as a book, between his eye and the window, parallel with one of the cross-pieces of the sash, so as to see only a narrow line of light, and a very small prismatic spectrum will be formed, containing, according to Brewster, all the different colours.

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light than in the broad light of day? What is the form of the pupil of the eye in man? Is it of the same form in the eyes of other animals? Why do the eyes of fishes have no aqueous humour? What is the form of the crystalline lens in their eyes? 452. Will all the rays of a pencil of light, transmitted through a double convex lens of glass, be brought to a focus at the same point? How is this avoided in the eye? What purpose does the iris serve in producing the same result? 453. Why are not the differently coloured rays separated by the parts of the eye in the same manner as when refracted by other media? How may it be shown that in some cases the several colours are separated by the parts of the eye?

454. As distinct vision is produced only when the light from objects is brought to a focus exactly on the retina, the eyes of persons may be defective by having too great refractive power, so as to cause the images to be formed, not on the retina, but a little in front of it; or by having too little refractive power, in which case the light is not brought to a focus soon enough, but tends to form the image a distance behind the retina.

455. The first defect is frequently seen in young persons, and is occasioned by too great a convexity of the cornea or crystalline lens. Such persons can see clearly only those objects which are very near them, and are therefore said to be *near sighted.* To enable them to see distant objects, it is necessary to make the rays diverge a little before entering the eye, by which means the image will be thrown back a little to the retina. This is accomplished by the use of spectacles with concave glasses, the effect of which is to separate the rays. Figure 210 represents an eye of this kind; A, a small object in front of it, and M N a double concave lens, to disperse (§ 373) the light before entering the eye. The dotted lines show the direction the rays would take if the lens was not interposed. It will be seen they intersect each other before reaching the retina, and at this point, but for the effect of the lens, the image would be formed; but by means of the lens to separate them a little, the image, *a*, is not formed until they reach the retina. Persons are sometimes met with, one of whose eyes is more convex than the other, which is a defect that requires the use of spectacles having one lens more concave than the other.

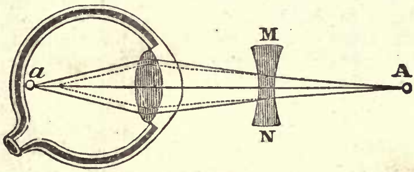

Fig. 210.

456. Near-sighted persons, who can see distant objects only by the use of concave glasses, never can have so large a field of view as is afforded by the unaided, perfect eye; their glasses enable them to see clearly only those objects which are situated in a small circle directly before them.

457. Most persons, on attaining the age of about forty-five, find their vision becomes indistinct from causes directly the reverse of those described above, in the case of near-sighted-

Quest. 454. In what two respects mentioned may the eyes of persons be defective? When the refractive power is too great, where is the image formed? Where when the refractive power is too small? 455. In whom is the first defect frequently seen? How is it occasioned? What objects only are seen clearly by such persons? What is necessary to enable them to see clearly? How is this accomplished? When one eye of a person is more convex than the other, how is the defect remedied? 456. Can near-sighted persons have as large a field of view as others? 457. At what age does the vision of most persons become indistinct from causes the reverse of

ness. The change is most likely to be first observed when they attempt to read very fine print, or to examine some minute object by candle-light. Though unable to see clearly when the object is held at the usual distance from the eye, they soon find that when it is removed a little farther off, the distinctness is improved. By this test persons may always know when this change is beginning to take place in their eyes.

458. This indistinctness of vision in aged persons is occasioned by the flattening which takes place in the cornea and crystalline lens. The light which enters the eye from near objects is not brought to a focus soon enough, but tends to form the image a little beyond the retina. This defect is remedied by the use of convex glasses, by which a slight convergency is given to the rays before they enter the eye. Let AB, figure 211, be an eye, the parts of which have become thus flattened by age; O a small object placed before it, and MN a double convex lens. The rays of light diverge from the object, O, and after being slightly bent inward by the lens, enter the eye, by which they are brought to a focus so as to form the image upon the retina, as shown by the dark lines. The dotted lines, as before, are designed to show the course the rays would take if the glass were removed. It will be seen that without the lens no image, or only an indistinct one, can be formed upon the retina, the focus being then at a distance beyond it.

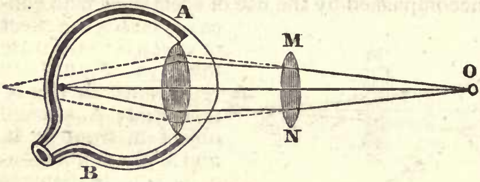

Fig. 211.

459. In most cases, persons whose eyes have become thus flattened by age can distinguish distant objects with as much clearness as in youth; or it is only in extreme old age, when the eyes have become much flattened, that glasses are required for this purpose. This is because the rays from distant objects are less diverging, or nearly parallel when reaching the eye, so that the convexity of the parts of the eye is still sufficient to bring them to a focus at the proper point. Instances have been known in which persons whose vision has been long indistinct, in consequence of the flattening of their eyes, have, in extreme old age, recovered their sight, and been able to

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those described above? When is the change likely to be first observed by them? How is their vision affected by moving the object a little farther from the eye? 458. By what is this indistinctness of vision occasioned? Where is the tendency to form the image? How is this defect remedied? Can a distinct image be formed without the lens? 459. Can aged persons usually see distant objects clearly? How is this explained? Will specta-

read even the smallest print without the use of spectacles; but, generally, the defect continues to increase with age, as long as the person lives. Of course, spectacles that answer well at one age become afterwards useless, and require to be changed for others that are more convex. Glasses that thus become useless are sometimes said to be too young for the person; and if he can see with them at all, it is only by holding the object at a considerable distance from him, as is the case with a person (§ 457) who has just arrived at the age when his natural vision begins to become indistinct.

460. Though spectacles are now found so important for aged persons, and are universally used, it is scarcely six hundred years since they were invented. We know from many passages of scripture which speak of the eye's becoming dim by age, as well as from profane history, that the eyes of persons in ancient times suffered the same change by age as they do now; but we have no reason to suppose they possessed any remedy for the defect. With what regret, therefore, must the ancients have observed the first appearance of this change in their eyes, which, in a few years, must render them comparatively useless, during the remainder of their days, for many of the most important purposes of life!

461. The *angle of vision* of a body is the angle made by two lines drawn from its opposite sides to the eye. It is sometimes called the *visual angle* of the body. Thus, let A B, figure 212, be an object placed before an eye, E; the angle made at E by the two lines A E and B E is the visual angle. The magnitude of this angle for any object, it will be seen, depends upon its distance from the eye; for if the object is removed farther off, as to A′ B′, the two lines drawn from its extremities to the eye approach nearer to each other, or, in other words, do not make so great an angle with each other as when situated at A B. So if it was placed nearer to the eye the angle would be larger, as will readily be seen.

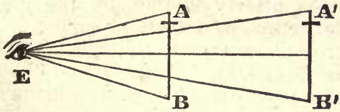

Fig. 212.

462. It is upon the size of the visual angle that the apparent magnitude of an object seen by the eye depends. As the rays of light from an object cross each other before reaching the retina, it is evident that the size of the image must always be in exact proportion to the magnitude of this angle; hence,

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cles that answer well for a person at one age afterwards become useless? What is the explanation? 460. How long have spectacles been used? Did the ancients possess any remedy for this defect of vision? 461. What is the *angle of vision* of a body? Upon what does the magnitude of this angle for any body depend? 462. Upon what does the apparent magnitude of a body

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when an object is situated at a distance, it must always appear smaller than when placed near the observer. This we well know to be the case. For this reason parallel lines seem to the eye to approach each other as they recede. Every one has observed this when looking at the rails upon a railroad, or at the rows of trees on the opposite sides of a straight turnpike. At a distance they seem much nearer together than in our immediate vicinity.

As we judge of the magnitude of a distant object by the magnitude of the visual angle, which, as we have seen, depends upon the distance of the object, it is plain that, before determining the size of the object, we must form some opinion of its distance.

Oftentimes we are aided in making our estimate of the magnitude of distant objects by other objects in their vicinity, the size of which is known; but if a body is entirely alone, and we have no means of determining its distance, we can form no correct estimate of its magnitude. A person lying upon his back in the open air perceives a fly passing before him, only a few feet from his eye, but for a moment he takes it to be a large bird high in the air, until some of its motions, or some other circumstance, reveals its true character. As soon as this is known he judges correctly of the distance, but before any circumstance occurred to indicate the real character of the object, or its distance, he was utterly unable, by the mere formation of the image on the retina, to determine either.

463. When an object is brought nearer to the eye than the least distance of distinct vision (§ 447), it becomes confused, because the eye is then unable to bring the rays to a focus on the retina; on the other hand, if it is carried so far from the eye as to diminish the angle of vision beyond a certain limit, it becomes invisible, the image being too small to produce the sensation of sight.

464. The eye always perceives an object in the direction from which the light from the object came on entering it, without reference to any change of direction it may previously have undergone, either by reflection or refraction; hence the image of an object seen in a plain mirror appears to be behind it. This is true, not only of an object considered as a whole, but also of all its parts. Suppose three small objects, A B C,

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depend? How do parallel lines that recede from the eye appear? What example, that is frequently seen, is mentioned? Do we, in judging of the magnitude of a body, first judge of its distance? How are we oftentimes aided in forming our estimate of a distant object? Why will a person looking upward in the open air often mistake a fly moving near him for a large bird at a distance? 463. Why is an object not seen clearly when brought nearer than the least distance of distinct vision? May an object be removed so far from the eye as to become invisible? 464. What is the direction in which an object always appears to the eye? Is this true, also, of all the

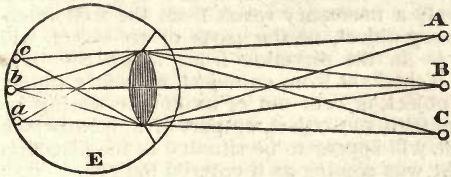

Fig. 213.

figure 213, placed one above another before an eye, E, so that all can be seen at the same time; the position of each is clearly seen by the direction in which the light comes to the eye. A is seen uppermost; then B a little below it; then C; though their images upon the retina, *a b c*, are in the reverse order, *a* being lowest, then *b* above it, then *c*.

465. Keeping these facts in view, we shall have no difficulty, it is believed, in deciding the question which has been so often discussed, why we see objects erect when their images are found inverted on the retina? For suppose the objects, instead of being separated, are united in one, as A B, figure 214. The part A, it is evident, must be seen above B, because of the direction in which the light comes from it, as really as if it were a separate object; and, for the same reason, the part B must be seen below A, though at the same time the image, *b*, of the part B is above *a*, the image of the part A. The same might, of course, be said of all the other points in the object, A B.

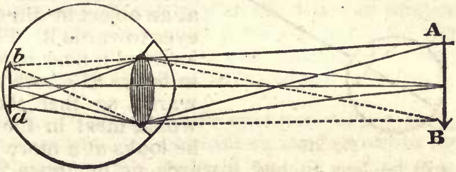

Fig. 214.

It appears, then, that if the eye always sees objects, and, of course, the different parts of objects, in the direction from which the light was coming from them to the eye at the time of entering it, the appearance of the object in an *erect* position is a necessary consequence of the *inverted* position of the image upon the retina, and that, if the image upon the retina was erect, to the eye the object must necessarily appear inverted.

466. To make this still plainer, let the line midway between A B and *a b*, figure 213, be the axis of the eye; then if *a* were not *below* the axis, the object A would not be above it, and if *b* were not above it, the object B could not be below it; or, supposing the two objects, A B, united together, and *a b*, the images of its parts, if the image were not formed in an inverted position on the retina, the eye could not see the object erect. That the eye should see objects erect when the image is formed

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parts of an object? As a necessary consequence of this, must the image on the retina be inverted, in order that the object may appear erect to the eye?

on the retina inverted, therefore, so far from being wonderful or mysterious, is only a necessary result from the well determined fact that every object, or the parts of an object, will always appear to be in the direction from which the light comes to the eye. If the light from an object, as before stated, or any part of an object, is bent out of its course during its passage to the eye, then the object, or part of it, from which the ray was emitted, will appear to be situated in the direction from which the light was coming as it entered the eye.

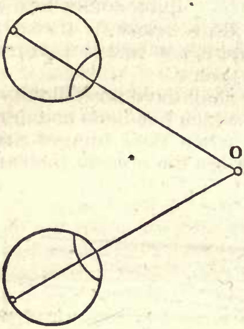

Fig. 215.

467. Another circumstance which has occasioned much discussion is the well-known fact that, though in persons whose sight is perfect there must always be two images formed, one on the retina of each eye, yet only a single object is seen. But it is believed this results entirely from the circumstance that when a person looks at an object he directs the axes of both eyes towards it. Thus, when a person looks at a near object, as represented in figure 215, both eyes are turned inwards, so that their axes produced would meet in the object, O. When he looks at a more distant object they will be less turned inwards, as in figure 216; and when the object is very distant, the axes of the eyes will be nearly parallel. As each eye, then, sees the object in the direction from which the light comes to it, it will appear to both in the same position, or, which is the same thing, but one object will be perceived. If, by any means, the axes of both eyes do not point precisely to the object, it will appear double.

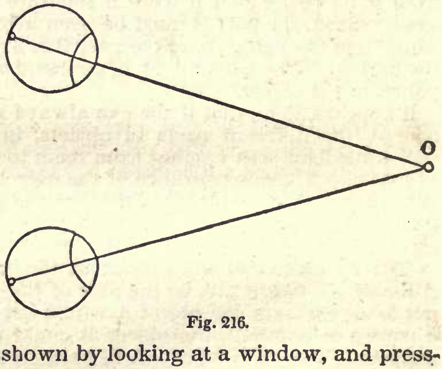

Fig. 216.

This may be easily shown by looking at a window, and press-

Quest. 467. Is there always an image of the object formed in each eye? Why, then, does not the object appear double? How are the axes of the eyes directed when looking at an object? What will be the effect if the axes of both eyes are not directed precisely to the object? How may this be shown?

ing gently with the finger against the lower side of one of the eyes, by which its axis will be turned a little upward; the horizontal bars will then all appear double: but if he presses against the right or left side of one of his eyes, the upright bars will be doubled.

468. Persons addicted to squinting, in which one or both of the eyes are turned out of their natural position, always see objects double, but by long experience they acquire the habit of attending to the sensation of only one eye at a time.

469. The optic nerve, as we have seen, enters the eye at a point about $\frac{1}{10}$th of an inch from the axis, on the side towards the nose; at this point there is a space of some extent, sometimes called the *punctum cœcum*, that is quite insensible to the action of light. To determine this, let a person place three small wafers about three inches apart on a sheet of white paper before him, and then, shutting the left eye, let him hold his head within six or eight inches of the paper, just so that he can, with his right eye, see all the wafers. Then, keeping his left eye closed, let him look attentively at the wafer at the left hand, and gradually remove his head from the paper to the distance of twelve or fourteen inches, and the middle wafer will entirely disappear, while the two at the outside are clearly seen.

470. Impressions made on the retina continue for a certain time, and therefore a person does not lose sight of an object by winking. If a red-hot iron, or a piece of burning charcoal, is made to revolve ten times a second, the eye will perceive a continuous circle of fire, which could not take place unless the impression on the retina remained a tenth of a second. Some writers affirm that it remains about one-seventh of a second.

Taking advantage of this property of the eye, the toy called the *thaumatrope* has been constructed. It consists of a circular piece cut out of a card, with two threads fixed to it on opposite edges, by twisting which between the thumb and finger it may be made to revolve with some rapidity. On the opposite side of the card two objects, having some relation to each other, are painted in the proper position, so that when the card is twirled round they appear connected, both objects, though on opposite sides of the card, being seen at the same time.

Quest. 468. Must persons addicted to squinting always see objects double? What habit is acquired by them which to some extent remedies the difficulty? 469. Where does the optic nerve enter the eye? What is meant by the *punctum cœcum?* How may the existence of such an insensible point be proved? 470. Do impressions produced on the retina remain for a time? If a piece of red-hot iron or burning charcoal is made to revolve ten times a second, what will be the appearance to the eye? What length of time, then, must the impression remain on the retina? What does the *thaumatrope* consist of? How is it used? Do we see both sides of the card at the same time?

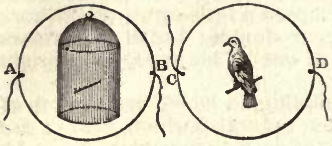

Fig. 217.

Let A B, figure 217, be one side of a circular card, with a cage painted upon it, and C D the other side, with the figure of a bird upon it. Now, when the card is twirled round as supposed, the bird will appear as if quietly perched in the cage, both figures being seen with equal distinctness. Sometimes a horse is painted on one side of the card and the rider upon the other, who, by the motion of the card, is made to appear seated properly upon his steed

This is occasioned by the permanence, for a time, of the sensation upon the retina; an image of the object upon one side of the card is first formed, and remains until the card is brought around so as to bring the figure upon the other side in view. The consequence is, as above stated, that both figures are really seen at the same time.

The intelligent student, who is unaccustomed to drawing, may easily prepare an apparatus of the kind by procuring pieces of paper with the necessary pictures, and pasting them on the opposite sides of the circular piece of card.

471. Persons are occasionally met with whose eyes appear to be insensible to particular colours, while they can distinguish all others with certainty, and their sight is, in other respects, perfect. In the cases which occur most frequently the individual confounds red with green, not only mistaking one for the other when presented to him alone, but even being unable to distinguish one from the other when presented to him together, considering them "a good match."

A tailor has been known to repair an article of dress, the colour of which was black, with crimson, not noticing the difference; and an officer in the navy once purchased a blue uniform coat and vest, with red breeches to match.

472. If a slip of white paper half an inch wide is held about a foot from the eye, and the attention directed to some object beyond on the opposite side of the room, after a few trials it will appear double. If, now, a candle is brought very near to one eye, so as not to shine upon the other, the slip of paper appearing on the side next to the light will seem to be of a yellowish red, while that on the other side will be of a pale green. If the slip of paper is made so wide that one image overlaps the other, one side will appear red and the other green, but the overlapping part will be white.

It will be observed that the two colours which are seen are complementary to each other, but no full explanation of the phenomenon has yet been given.

Quest. 471. What is said of the eyes of certain persons in respect to certain colours? In the cases which occur most frequently, what colours are mistaken for each other?

473. The eyes of most of the larger land animals are similar to those of man, but they are often more or less modified, to adapt them better to their particular modes of life. Several of these peculiarities in the eyes of animals have already been alluded to (§ 451).

474. The eyes of insects are generally compound; that is, each eye is composed of many separate eyes, situated side by side. This is the case with the eye of the common house-fly, the beetle, butterfly, and the dragon-fly. This appears to be designed to compensate for the want of motion in the eye, which, in such cases, is always fixed. They are thus enabled to see in different directions at the same time.

The eye of the butterfly, when examined by the microscope, is found to be divided into an immense number of little squares, by a firm partition, in each of which is a perfect eye. In the yellow beetle these little cells are six-sided, like the cells of a honey-comb, but much smaller.

The eyes of insects being so small, they can, no doubt, perceive much smaller objects than man is capable of seeing, but at the same time their vision cannot extend so far.

OPTICAL INSTRUMENTS.

Several optical instruments have already been in part described, as the different kinds of mirrors and lenses; but others of great importance, mostly formed of combinations of these, remain to be noticed.

475. *Photometers.*—An instrument designed to determine the relative intensities of different lights is called a *photometer;* several of which have been invented, but no one of them has come into general use. There seems, indeed, to be no better method to determine the relative intensities of two or more lights than that proposed by Count Rumford. Let us suppose we are to compare the intensities of the light from two lamps. They are to be taken into a room from which all other light is excluded, and placed in front of a white screen; some opake object is then to be held between them and the screen, so that the shadows formed by the two lamps may fall side by side upon the screen. If the two shadows are not now of equal intensity, one or the other of the lamps is to be moved backward or forward until they are made as nearly equal as possible, and then the distance of each lamp from the screen is to be measured. The intensities of the two lights will be to each as the squares of these distances. Suppose, for instance, that

Quest. 473. Are the eyes of most land animals similar to those of man? 474. Of what are the eyes of most insects composed? For what does this appear designed to compensate? What is the appearance of the eye of the butterfly when examined by a microscope? 475. What is the design of the *photometer?* What is the method proposed by Count Rumford for determining the relative intensities of two or more lights?

when the shadows formed by the two lights are equal, the distance of the first from the screen is 3 feet and that of the second 4 feet; their comparative intensities will then be as 9 to 16.

476. *The Kaleidoscope.* — The *kaleidoscope* is an instrument for creating and exhibiting beautiful forms. It is formed by placing two pieces of painted glass together in such a manner that the angle between them shall be an exact or aliquot part of a whole circumference, or 360 degrees, and enclosing them in a case so as to exclude all light except that from the proper direction. Let A and B, figure 218, be two plates of glass 8 inches long and 2 inches wide, painted black on the outside, and placed as in the figure, making the angle, C, between them, 60°, or just one-sixth of 360°. If the eye be now placed

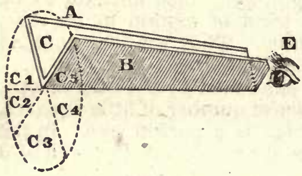

Fig. 218.

at E, so as to look through between the plates, by the various reflections of the plates from side to side, the angle or sector C, will appear to be multiplied five times, producing the circle of six sectors, C, C 1, C 2, C 3, C 4, C 5. If any small object, as a piece of painted glass, is placed in the sector C, it will, of course, appear in each of the other sectors, C 1, C 2, C 3, &c., forming a symmetrical figure around the centre. The plates are usually enclosed in a cylindrical case, and several pieces of glass of different colours are placed in C; these, by turning the instrument, are constantly changing their position, forming around the centre of the circle an almost endless variety of beautiful figures.

477. *The Camera Obscura.* — The camera obscura is an instrument for forming images of objects, as of a landscape, on a screen of paper or other substance within it. The name means simply *darkened chamber*, and is applied to the instrument because this is a necessary part of it; but, as we shall hereafter see, it may be a large room to contain a number of persons, or very small, so as only to receive the screen on which the image is formed, the observer being obliged to look in through a small aperture.

478. The simplest camera obscura that can be formed consists merely of a small aperture in the window-shutter of a darkened room, before which a screen of white paper is to be held. Rays of light received through a small aperture upon a screen tend to form an image of the object from which they proceed, and not an image of the form of aperture, as might

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Quest. 476. What is the *kaleidoscope?* How is it formed? 477. What is the *camera obscura?* What is the meaning of the name? Why is it used? 478. Of what does the simplest camera obscura consist? Will rays of light passing through a small aperture form an image of the object from which

be supposed. Thus, if the light of the sun be admitted into a room otherwise dark, through a small hole in the shutter, a round image of the sun will be produced upon a screen, or a sheet of paper, held at a little distance from the hole, whatever may be its form. If the screen is held too near the hole, however, this will not take place, but a luminous spot will be seen of the general form of the aperture, with its angles more or less rounded, depending upon its size and the distance the screen is held from it. The rounding of the angles is evidently to be considered as an approximation to the form of the sun. To try this experiment, let a large hole be made in the wooden shutter of a room, and covered with a sheet of lead, in which smaller apertures may be cut at pleasure, of any form desired. If a mere slit is made in the lead, when the screen is held near it an elongated image of the sun will be formed; which, however, becomes more nearly circular as the screen is carried farther off, until, at length, a perfectly circular image is produced. If the aperture is square or triangular, or whatever its form, the same result will be obtained. If a number of small pin-holes are made, each will give a distinct image of the sun if the screen is held near them, but as it is moved farther off they will increase in size and overlap each other until they combine to produce a single large and well-defined image, just as if the whole space of the shutter in which they are contained had been removed, except that it is less brilliant. If a circular aperture is made, and one or more lines drawn across it, when the screen is held beyond a certain distance no shadow of the lines will be seen, but as perfect an image of the sun as if they had not been there.

479. To understand clearly the reason of this, it is to be observed that the sun presents towards us a disc or surface of a certain extent, from each point of which rays are emitted, so that pencils of them enter even small apertures, slightly diverging, and crossing each other. Now a larger aperture, as one a quarter of an inch square, may be considered as made up of a multitude of small ones, all united together; and as each of these small apertures would produce an image of the sun, the large image may be supposed to be composed of a multitude of small images, all blended together. Thus, if we form a small square, A B C D, figure 219, and from points in its sides draw several small circles, it will be seen the outline of the whole very

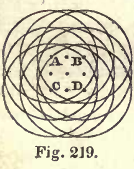

Fig. 219.

they proceed? Will this be the case whatever may be the form of the aperture itself? What will be the effect if the screen is held too near the aperture? How may the experiment be tried? If a number of small pin-holes be made in the shutter, will the light from the sun still form an image of the sun upon a screen within? Must the screen be held at a distance from the aperture? 477. Do the rays from the sun cross each other in passing through

nearly approximates the form of the circle; and the deviation from the circular form becomes less and less in proportion as the diameter of the small circles is increased. Now, as has just been stated, any aperture, whatever may be its form, may of course be considered as made up of many small apertures; and the result should therefore be the same, viz: the production of a circular image of the sun.

If these experiments are made during an eclipse of the sun, the images will always be of the same form as the disc of the sun towards us. It is said that during an eclipse of the sun an image of his disc has been seen projected on the ground through the small opening among the leaves of trees.

480. But the images of other objects may be formed by transmitting light through small apertures into a darkened room, as well as that of the sun. Thus, let B, figure 220, be a bird standing upon a branch of a tree at a little distance from the window-shutter, S, of a darkened room; if the light is admitted only through a small hole in the shutter, and a sheet of paper is held near it, a beautiful inverted image of the bird, A, will be formed upon it. If the aperture is made too large the image will still appear, but it will be confused; and if too small, it will be indistinct for want of light.

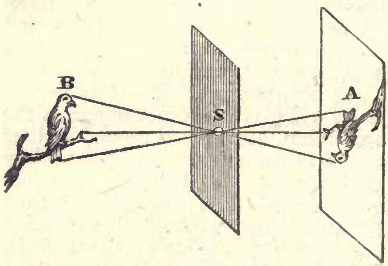

Fig. 220.

481. But a much better image will be formed by placing in the aperture a small double convex lens; the aperture may thus be made much larger, and therefore a greater quantity of light will be admitted, by which the brilliancy of the image will be greatly increased. If the sheet of paper is oiled before using it, so as to make it translucent (§ 334), the image will be seen with nearly equal distinctness on both sides at the same time, and the experiment may be conveniently shown to a large audience in the room. Sometimes the lens is fitted into a hollow ball, which is so adjusted in the shutter as to allow of being turned in different directions, and thus different portions of the landscape in front may be successively exhibited.

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an aperture? May a large aperture be considered as made up of many small ones? What will be the result if the experiment is made during an eclipse of the sun? 480. May the images of other objects be formed in the same manner as those of the sun? What will be the effect if the aperture is made too large? 481. What will be the effect if a double convex lens is placed in the aperture? Why will the image be more brilliant? What is the appa-

Persons standing in front of it will have their images painted so distinctly on the screen within the room that they can be easily recognized. Such a piece of apparatus is called a *sci-optic ball.*

482. The common portable camera obscura is constructed essentially on the same principle as the above, but is adapted for tracing upon paper the outlines of landscapes and other objects, in front of which it may be placed. It is usually made of a square box, A B C D, figure 221, in the top of which is fitted a tube containing a lens and a plane mirror, M, inclined so as to reflect the light from an adjacent landscape directly through the lens to the bottom of the box, as indicated by the dotted lines. Having placed the instrument upon a table before the landscape or building, the form of which is to be traced, and adjusted the parts in a proper manner, a well-defined image is formed upon the paper on the bottom of the box. In the side A C is a large opening, through which the person has access to his paper, and all extraneous light is excluded by means of a black curtain, L, which is drawn over him. The person stands, as will be seen, with his back towards the object, and traces it accurately at his leisure, by means of the image on the paper before him. To diminish spherical aberration (§ 376), instead of a double convex lens, a meniscus is often used, as represented in the figure. The tube containing the lens is made moveable, in order to adjust the lens to the proper distance from the paper, which will depend upon the distance of the object from the mirror.

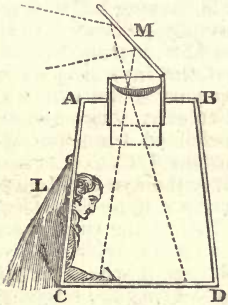

Fig. 221.

An improved form of this instrument has been constructed within a few years past, in which the lens and mirror are combined in a single piece. This consists of a triangular prism, A B C, figure 222, with one of its sides, A B, convex, and another, B C, concave; so that the rays of light, on entering the convex side, which is placed towards the object, are made to converge, and are totally reflected downward by the internal surface, A C.

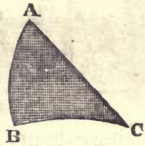

Fig. 222.

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ratus called when the lens is fitted in a hollow ball and placed in the shutter, so as to be capable of being turned in different directions? 482. For what is the common portable camera obscura adapted? Where is the paper to be laid on which the image of the object is to be traced? For what purpose is there a large opening in one side of the box? How is the light excluded? Why is a meniscus used instead of a double convex lens? What kind of a glass is used in the improved apparatus illustrated in figure 222?

As the side B C is made concave, the effect is the same as that of the meniscus, to diminish the aberration. It is plain that the concavity of the side B C should be less than the convexity of A B, in order that the rays may be made to converge to a focus on the paper.

483. The *camera lucida* is an instrument used for the same purpose as the camera obscura; that is, for making drawings of landscapes, buildings, and other objects. It is made with a single glass of the form A B C D, figure 223, having all its surfaces carefully polished. If an object, as M N, is placed before it, so that the rays may enter the lower part of the side A D perpendicularly, they will be totally reflected from the internal surface, D C, to C B, and from that to the eye at E, causing the object to appear as if situated at *m n*. If, now, the eye is placed near the angle B, so that one half of the pupil may receive the light directly from the paper on the table at *m n*, the outline of the object may be traced upon it with a pencil. The effect of the instrument, therefore, is to bring the reflected image of the object upon the paper on which it is to be traced. The glass is usually enclosed in a socket of brass, except those parts through which the light is to pass, and supported by a rod, with a clamp and screw, to attach it firmly to the side of a table.

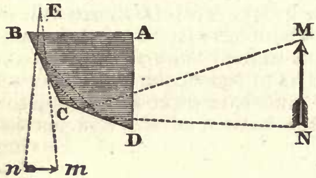

Fig. 223.

484. *The Magic Lantern.*—This is, to a considerable extent, the reverse of the camera obscura. By the camera obscura a diminished image of a landscape or other object is formed on a screen within, but by means of the magic lantern a magnified image of a small object is formed on a screen without. The objects used are generally small and nearly transparent paintings, made on glass; an entirely opake object cannot be used. This instrument, as usually made, consists of a tin box, painted black inside and out, with a lamp, L, figure 224, and a reflector, M N, by which a strong light is thrown upon the object, so as to produce a brilliant image. On the side of the lamp opposite the reflector is a tube, A B, having a large plano-convex-lens, A, and a

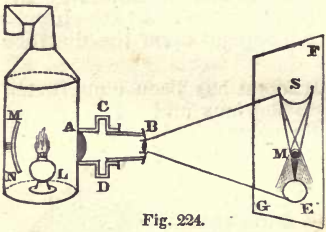

Fig. 224.

Quest. 483. For what purpose is the *camera lucida* used? What is the effect of this instrument? 484. How does the *magic lantern* differ from the camera obscura? What are the objects generally used in this piece of apparatus? Of what does this instrument consist? What is the design of the

smaller double convex lens, B. Through C D is a slit for introducing the paintings, of which there are generally several on the same piece of glass; so that one after another may be exhibited by sliding through the piece of glass. The design of the lens A is to concentrate the strongest light possible upon the object, which is to be situated a little beyond the focus of the double convex lens, B. The rays of light from the object or picture are then refracted by the second lens, B, and brought to a focus upon a screen, G F, placed at the proper distance, producing on it an inverted image. The lens B is usually contained in a smaller tube, which slides in the other, so that it may be drawn out or pushed in at pleasure, to accommodate the instrument to the distance of the screen. The farther off this is placed, the more will the object be magnified, but the light being spread over so great a surface, if the image is too much magnified, it becomes indistinct. This instrument is always used in the evening, or in a dark room. The drawing supposed to be in the lantern in figure 224 is a representation of an eclipse of the sun—S, the sun; M, the moon; E, the earth.

485. The *solar microscope* is constructed on the same principle as the magic lantern, except that it is adapted for using the light of the sun instead of that of a lamp. The light is first reflected into the instrument, which is placed in a hole in the window-shutter, by means of a mirror so contrived as to be moved steadily in the proper position for reflecting the light of the sun, in the required direction, at any hour near the middle of the day. The lenses are exactly the same as those of the magic lantern, except that the one corresponding to B, figure 224, by which the image is formed, is usually much smaller, and magnifies more.

The solar microscope is generally used for forming images of objects in natural history, as small insects, parts of plants, &c. No light, of course, must be admitted into the room, except that which forms the image.

486. *The Single Microscope.*—The single microscope, or *magnifying-glass*, is simply a double convex lens, through which the observer looks at the object. When used, no image is formed, but the eye looks directly at the object itself. It is often fitted up in a case of horn or shell, so as to adapt it to be carried in the pocket.

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large lens, A? Why is the second lens, B, usually contained in a smaller tube, which slides in the larger? How will the magnitude of the image be affected by increasing the distance of the screen? Will the light be as brilliant? 485. How is the *solar microscope* constructed? In what does it differ from the magic lantern? For what purpose is the solar microscope generally used? 486. What is the *single microscope*, or *magnifying-glass*? How does the eye look at the object when it is used?

487. The reason why the double convex lens magnifies the apparent size of objects may be illustrated as follows:—Let L, figure 225, be a double convex lens, and A B an object seen through it by the eye, E. Let the dark lines drawn from the extremities, A and B. to the lens be the outermost rays that reach the eye; in passing through the lens they are bent inwards towards the axis, and the eye sees the points from which they were emitted in the direction from which they were coming when entering it. That is, the eye will see the extremities, A and B, of the object as if situated at A′ and B′; and, as the points between A and B will be affected in the same manner, it is evident that the object, A B, will appear to be enlarged to A′ B′.

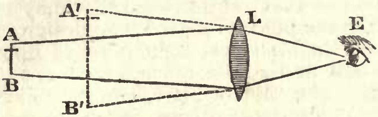

Fig. 225.

488. By means of the double convex lens we are able to see objects much nearer the eye than we otherwise could: indeed, it is only when seen at a less distance than in ordinary vision that any magnifying effect is produced. The magnifying power of such a lens is determined by dividing the least distance of distinct vision (5 inches) by the distance at which it is seen by the use of the glass; or, which comes to the same thing, by the focal distance of the glass. Thus, suppose a magnifying-glass enables the eye to see clearly an object at the distance of 2½ inches, it will appear twice as large as when viewed by the naked eye. If the object, by the use of the glass, can be seen when held only one inch from the eye, it will be magnified five times; that is, it will appear five times as large as when viewed by the unassisted eye.

489. If a small object is viewed through a perforation in a piece of paper, or other thin opake substance, it will appear magnified. This is because the more diverging rays from the object, which would otherwise enter the eye, are excluded by the paper, and the object is seen by the less divergent rays; so that it can, in consequence, be brought nearer the eye. Let O, figure 226, be a small object seen by the eye, E, through a perforation in a piece of black paper, P; the perforation in the paper being smaller than the pupil of the eye, the outside and

Quest. 487. What is illustrated in figure 225? How does it appear that the object will be seen magnified? 488. Are we able, by means of the magnifying-glass, to see objects when held nearer the eye than we otherwise could? How is the magnifying power determined? If, by means of a double convex lens, the eye is enabled to see an object at the distance of 2½ inches, what will be its magnifying power? If the object is seen distinctly at the distance of an inch only, how much will it be magnified? 489. Will a small object appear magnified if seen through a small aperture made in some opake substance? How is it explained?

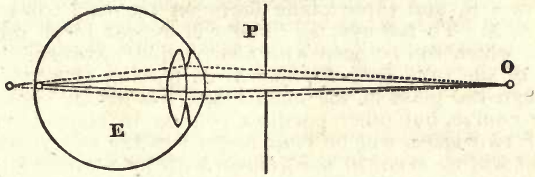

Fig. 226.

most divergent rays of the pencil that would otherwise enter the eye are now intercepted, and the object is seen by the smaller pencil, represented by the continuous lines; and it may, therefore, be brought nearer the eye. If the outside rays, represented by the dotted lines, were permitted to enter the eye, they would not be brought accurately to a focus on the retina, but would tend to form an image a little beyond it, by which the vision would be obscured. It is this circumstance that prevents most persons from seeing objects clearly when brought nearer than about 5 inches.

490. It should be noted here, that always when speaking of the magnifying power of any instrument, the *linear* magnifying power is meant, unless it is otherwise stated. Thus, when it is said that the magnifying power of a glass is 2 or 5, as above, it is meant that the apparent length of a straight line will be increased in that proportion. At the same time, the *surface* will be magnified in a much greater ratio, as the expert arithmetician will instantly see. Thus, when the linear magnifying power of an instrument is 2, the surface will be magnified twice 2, or 4 times; and when the linear magnifying power is 5, the surface will be magnified 5 times 5, or 25 times. The superficial magnifying power is always found by squaring the linear magnifying power.

These remarks are intended to apply to all instruments, both microscopes and telescopes.

491. If a piece of glass or other transparent substance, ground and polished, with several plane faces, is held between the eye and some small object, there will be seen as many objects as there are faces to the glass. This is called a *multiplying glass*. Let M N, figure 227, be a glass of this kind, having a plane surface towards

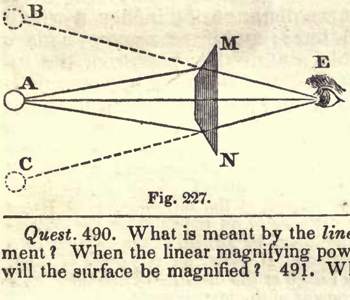

Fig. 227.

Quest. 490. What is meant by the *linear* magnifying power of an instrument? When the linear magnifying power of an instrument is 2, how much will the surface be magnified? 491. What is the *multiplying glass?*

the eye, E, and three plane faces on the side towards the object, A. To the eye, E, there will appear to be three objects, which will be seen with nearly equal clearness. A portion of the rays from the object, A, passing perpendicularly through the glass at the middle face, will not be bent out of their course, but other portions, coming in contact with the other two faces, will be bent inward to the eye, so that the object will be seen, in accordance with laws already pointed out (§ 444), in the directions B and C. Glasses of this kind are sometimes made with a great number of faces, through each of which the object, if small, will be seen.

492. *The Compound Microscope.*—The compound microscope receives its name from the fact that it is composed of two or more lenses, whereas, in the single microscope, there is but one. Let A B, figure 228, be a compound microscope, having

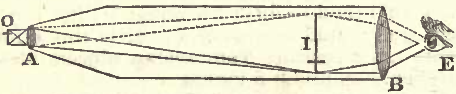

Fig. 228.

its object-glass, A, which is towards the object, and eye-glass, B, which is towards the eye; and let O be a small object before it. By means of the small object-glass an image of the object will be formed within the tube, as at I, which will be as much larger than the object as it is farther from the lens (§ 375). Thus, suppose the object, O, is only a quarter of an inch from the centre of the object-glass, A, while the image, I, is formed at the distance of 2 inches, it will then be 8 times as large as the object. Now, by means of the eye-glass, B, we view the image precisely as we do the object with the single microscope; and if, by means of this, we are able to see the image at the distance of one inch, while the least distance of distinct vision to the unaided eye is 5 inches, the whole magnifying power of the instrument will be 5 times 8, or 40. If the distance of the object from the object-glass was only $\frac{1}{10}$th of an inch, and the image formed at the distance of 6 inches, it would be magnified 6 times 10, or 60 times; and if the same eye-glass were used as before, the whole magnifying power of the instrument would be 5 times 60, or 300. If an eye-glass of only half this focal distance, or $\frac{1}{20}$th of an inch, were used, its magnifying power would be 600.

Quest. 492. How many lenses are there in the *compound microscope?* What is the object-glass? What is the eye-glass? What is the office performed by each? Will the image formed by the object-glass be larger or smaller than the object? If the distance of an object from the object-glass be one-tenth of an inch, and the image be formed at the distance of 6 inches, how much will it be magnified? If, now, an eye-glass is used, which enables the eye to look at the image at the distance of one inch, how great will be the whole magnifying power of the instrument?

493. The *field of view* of an instrument, as a microscope, or telescope, is the field or space the eye is capable of taking in at a single view when using it. This, in a microscope with only two glasses, as described above, is exceedingly small; and to increase it, a third lens has been added, called a *field-glass.*

To make this plain, let us suppose an attempt is made to construct the instrument without the field-glass. Let A, figure 229, be the object-glass, and B the eye-glass; O is a small

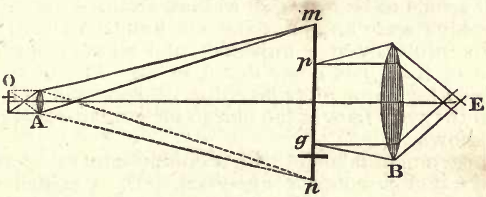

Fig. 229.

object placed before it, of which a magnified image, *m n*, is formed. This image, it will be seen, exceeds the diameter of the object-glass, B, and the rays from a part of it only, which lies between *p* and *g*, can reach the eye at E. Though the object may not exceed $\frac{1}{20}$th or $\frac{1}{50}$th of an inch in length, therefore, only a part of it will be seen by the eye.

But let us now introduce the field-glass, as F, figure 230; the rays which would, if this were not used, form the image *m n*, as before, are now brought sooner to a focus, and produce the image *p p*, the whole of which will be seen through the eye-glass, B. The image being diminished, the object will, as a matter of course, appear less magnified than it would otherwise be; but the field of view is so much enlarged that, on the whole, the instrument is found to be much improved.

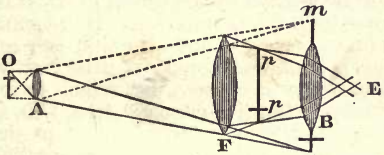

Fig. 230.

The glasses of the compound microscope are usually carefully adjusted at the proper distances in a tube of brass, with an apparatus for holding the objects to be examined, and a concave mirror or convex lens for illuminating them strongly; and the whole attached to a proper support.

A camera lucida is also often added to the larger instrument,

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Quest. 493. What is meant by the *field of view* of an instrument? What is the object of the *field-glass?* Will the object appear as much magnified by the use of the field-glass as it otherwise would be?

for the purpose of making drawings of objects as they appear when viewed by them.

494. *Telescopes.*—Telescopes are the reverse of the compound microscope; their design is to enable us to view objects which are so distant as not to be seen at all by the unassisted eye, or but indistinctly.

Telescopes are of two kinds, the *reflecting* and the *refracting*, both of which are much in use, each possessing its peculiar advantages.

495. It seems to be tolerably well ascertained that telescopes of some kind were known about six hundred years ago, but they were probably very imperfect, and no very accurate description of them has come down to us. The *Galilean* telescope, from the name of its inventor, Galileo, who first made it public in the year 1609, is the oldest, the construction of which is now known.

This instrument is made with a double convex object-glass, A B, and a double concave eye-glass, C D, as shown in figure 231. Let M N be an object situated at a distance before it, so

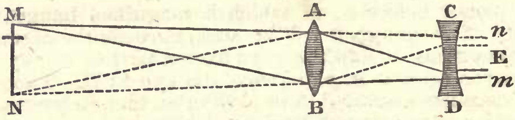

Fig. 231.

that an inverted image will be formed by the object-glass, A B, at *m n*, if the concave eye-glass, C D, is removed. By placing a screen at this point the image received upon it might be examined directly, but the eye, placed at E, could not perceive the object, since the rays would enter it converging, which is inconsistent with distinct vision. But if a concave lens, C D, is introduced, the virtual focus (§ 372) of which shall be at the point where the image would fall, the rays will emerge parallel, and produce a distinct image in the eye.

This telescope, in consequence of the small field of view it affords, is not used now, except for viewing objects at a moderate distance, as in a large room or theatre. It is then called an *opera-glass.* Usually two of them are attached to each other, at such a distance that one eye may be directed through each at the same time.

496. If, instead of the concave lens for an eye-glass, the convex lens is introduced, the instrument becomes a common

Quest. 494. What is the design of the telescope? How many kinds of telescopes are there? In what do they differ from each other? 495. How long have telescopes been in use? What is the old-st telescope, the construction of which is now known? If the eye-glass were removed, why could not an eye placed at E, fig. 231, see the object? What purpose is served by the eye-glass? For what purposes only is this instrument now used? 494. What change only is required in this telescope to convert it into an astrono-

astronomical telescope; but the eye-glass must then be placed farther from the object-glass, as will shortly be shown, and the object will be seen inverted. The astronomical telescope is represented in figure 232, in which A B is the object-glass and

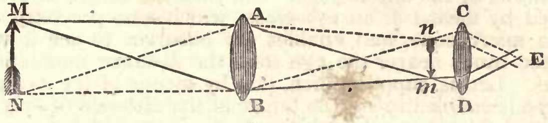

Fig 232.

C D the eye-glass. The object-glass is formed with a long focal distance, but the eye-glass with a focal distance much less; upon this depends its magnifying power. Let M N be an object placed at a distance from the object-glass, so as to form an inverted image, *m n*, at its principal focus, in the manner already described (§ 375); this image will then be viewed by means of the eye-glass, C D, just as in the compound microscope.

Indeed, there is a striking resemblance between the astronomical telescope and the compound microscope. In the latter instrument a magnified image of the object is formed, which is viewed by means of the eye-glass, as a single microscope; but in the telescope a diminished image is formed, which is viewed in the same manner as before. But though the image of the object in the telescope is very much less than the object itself, yet its apparent magnitude is often greatly increased, since we are enabled to inspect the image at a much less distance from the eye than the object is.

497. In order to determine the magnifying power of the telescope, let us first suppose the image, *m n*, received upon a screen; this image will be as much less than the object as it is nearer the lens, A B, than the object is (§ 375), but if the eye were situated in the lens, A B, the apparent magnitude of both would be the same. This appears from the fact that at this point both would subtend the same angle, as will readily be seen by examination. Let us suppose, now, that the focal distance of the object-glass, that is, the distance from A B to *m n*, is 10 inches, and that the eye is so placed as to view the image at the least distance of distinct vision, which is 5 inches; its

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mical telescope? Upon what does the magnifying power of this telescope depend? What purpose is served by the object-glass, and what purpose by the eye-glass of this telescope? What is said of the resemblance between this telescope and the compound microscope? If the image of an object in a telescope is smaller than the object itself, how does it appear that its apparent magnitude may be increased by it? 497. If we suppose the eye placed in the object-glass of the telescope, and the image received upon a screen, what will be the comparative apparent magnitude of the object and image as seen by it? How does this appear? If the focal distance of the object-glass be 10 inches, and the image be viewed directly by the eye at

apparent magnitude would evidently be twice as great as that of the object. If the focal distance of the object-glass were 5 feet, or 60 inches, then, to the naked eye placed at the distance of 5 inches, the image would have twelve times the apparent magnitude of the object itself. But then the image is always viewed by means of an eye-glass, which acts precisely as a single microscope, and enables the observer to see it when situated much nearer the eye than the distance mentioned, 5 inches. Let us suppose, then, that by means of the eye-glass the eye is enabled to see the image at the distance of only one inch, by which it would, of course, be magnified 5 times; the whole magnifying power, in the last case mentioned above, would be 5 times 12, or 60 times. But this same result might evidently have been obtained by dividing the focal distance of the object-glass, 60 inches, by the focal distance of the eye-glass, 1 inch; hence, to find the magnifying power of the astronomical telescope, we have only to divide the focal distance of the object-glass by the focal distance of the eye-glass.

As the eye-glass should be placed so as to have the image in its focus, it is evident the distance of the two glasses apart ought to be just equal to the sum of their focal distances. Generally the object-glass is considerably the largest, and the eye-glass is placed in a tube somewhat smaller than that which contains the former, so that it may be moved backward and forward as may be found necessary in viewing objects at different distances, or to accommodate the instrument to the eyes of different persons. In this telescope it is evident that objects will always be seen inverted; but for astronomical purposes this is of no consequence, since their true place and position can be just as readily determined.

498. By adding to the astronomical telescope two other lenses of the same focal distance as the eye-glass, the *terrestrial telescope*, or common *spy-glass* is produced. The design of these additional lenses is merely to cause the object to be seen erect: an inverted image of the object is first formed, as in the instrument just described, and then an inverted image of this image, which is seen by the eye as before.

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the distance of 5 inches, how would the apparent magnitude of the object and image compare? How does the eye-glass act? Does it enable the observer to see the image at a less distance from the eye than 5 inches? If the focal distance of the object-glass be 60 inches, and by means of the eye-glass the image may be viewed at the distance of 1 inch only, what would be the magnifying power of the instrument? How is the magnifying power of the telescope to be found? What distance apart must the two glasses be placed? Which of the two glasses is usually largest? Why is the eye-glass placed in a tube so as to allow of being moved backward and forward? How will the object always be seen in this telescope? 498. How does the *terrestrial telescope*, or *spy-glass*, differ from the astronomical telescope just described? What is the design of these two additional glasses? What is

Figure 233 represents the glasses of the terrestrial telescope removed from the tube. A B is the object-glass, by means of

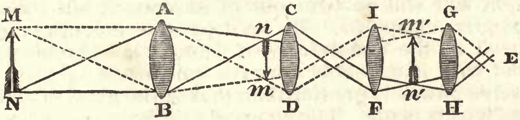

Fig. 233.

which an image, *m n*, of the object, M N, is formed in its focus; C D corresponds to the eye-glass of the astronomical telescope, and is so placed that the image, *m n*, is in its focus. From C D the rays emerge parallel, and by the second eye-glass, I F, are again brought to a focus, forming an image, *m′ n′*, of the first image, which is erect like the object. This last image is seen by the eye at E, magnified by the third eye-glass, G H. The magnifying power of this telescope is found in the same manner as in the astronomical telescope, by dividing the focal distance of the object-glass, A B, by that of the first eye-glass, C D; the effect of the other glasses, as already intimated, being only to reverse the position of the first image.

These three eye-glasses are usually fixed in a tube, in the proper position with respect to each other, so as to slide backward and forward in the tube which contains the object-glass, A B. As a portion of light is lost at every refraction, objects are seen less distinctly with this instrument than with the astronomical telescope; but, as it shows the objects erect, it is preferred for use in viewing terrestrial objects.

Both astronomical and terrestrial telescopes are subject to all the difficulties attending upon spherical (§ 376) aberration and the dispersion of the colours by refraction, but our limits will not allow us to enter upon a detailed examination of the different methods adopted for obviating them. A few remarks only upon *achromatic* telescopes can be introduced. They are so called because the object is seen in them destitute of every other but its natural colours.

499. Since the primary colours of light are always separated more or less when it is refracted, this effect must follow when refraction is produced by means of a lens, as well as when the prism is used; but the colours, instead of being situated as in the solar spectrum (§ 387), will be arranged in concentric rings.

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represented in figure 233? To what does the lens C D correspond in the astronomical telescope? How is the magnifying power of the terrestrial telescope found? Are objects seen as distinctly by means of the terrestrial as by the astronomical telescope? What reason is given? Are telescopes subject to the difficulties arising from spherical aberration and the dispersion of the primary colours of light? What is an *achromatic* telescope? 499. When the primary colours of light are separated by the action of a lens, how will they be arranged? To destroy the colours produced by a double convex

We have seen that when two similar prisms are used, having different dispersive powers, and placed in opposite positions, the light will still be bent out of its course, but the colours will nearly disappear. To destroy the colours, therefore, produced by the double convex lens, it is only necessary to connect with it a double concave lens, made of glass whose dispersive power is greater than that of the glass of which the convex lens is made. The concavity of the concave lens being somewhat less than the convexity of the other, the rays will still be brought to a focus, though at a greater distance from the glass than if the concave lens were not used, forming a colourless or *acromatic* image, that is, an image of the natural colour of the object.

Fig. 234.

It is found that flint glass (that of which drinking-glasses are usually made) and crown glass (common window-glass) answer well this purpose, the dispersive power of the former being considerably greater than that of the latter. Figure 234 represents an achromatic object-glass, A B being a convex lens of crown glass, and C D a concave lens of flint glass.

500. The *reflecting telescope*, instead of the object-glass, contains a concave reflector, or speculum, in the focus of which the image is formed, and is viewed by means of an eye-glass, in the same manner as in the refracting telescope.

There are several kinds of reflecting telescopes, as the *Gregorian*, *Newtonian*, *Herschelian*, and the *Cassegrainian*, each of which has received its name from its inventor.

Figure 235 represents the *Gregorian* telescope, in which A B is a concave metallic speculum, with a hole in its centre and

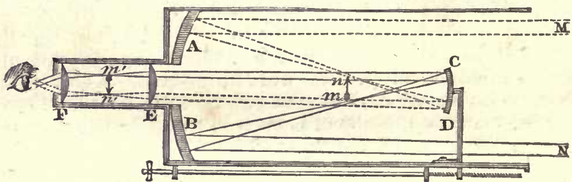

Fig. 235.

C D a much smaller one, supported so as exactly to front the first. By means of a screw, W, the small speculum is moved backward and forward, so as to adjust it at the proper distance from A B, which should be a little greater than the sum of their

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lens, what only is necessary? Must the concave or convex lens have the greater dispersive power? Must the concavity of the concave lens equal the convexity of the convex? What two kinds of glass are found to answer the purposes required? 500. How does the reflecting telescope differ from the refracting? What different kinds of reflecting telescopes are mentioned? How many reflectors has the Gregorian telescope? Where is the image

focal distances. E and F are eye-pieces, which are usually plano-convex lenses, having their convex surfaces turned towards the object. Now suppose rays of light, M N, from the extremities of some distant object, to strike upon the large speculum, they will, of course (§ 355), be reflected to a focus, and will form an inverted and diminished image, *m n*, in front of the small mirror, a little farther from it than its principal focus. By means of the small mirror, light from this image, as from a new object, will be again reflected through the hole in the large mirror, and a second erect image formed, *m′ n′*, which is viewed magnified by the eye-glass, F. The lens E might be dispensed with, but is always used for the same purpose as the field-glass (§ 493) in the compound microscope.

The *Cassegrainian telescope* is precisely the same as the Gregorian, except that the small mirror, C D, is made convex, so that the length of the instrument is somewhat diminished, the virtual image of the small mirror being formed behind it.

The *Newtonian telescope* was invented by Sir Isaac Newton, and is shown in figure 236. It consists of a concave speculum,

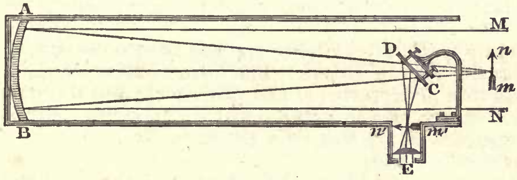

Fig. 236.

A B, placed at one end of a tube, from which rays of light, M N, from an object are reflected so as to form an inverted image, *m n*, in its focus; but a small plane mirror, C D, inclined to the axis of the instrument, is interposed, and it is reflected to *m′ n′*, where it is viewed by means of the eye-piece.

501. It only remains for us to describe the telescope of Herschel, which, for astronomical purposes, seems at present nearly to have superseded all others. Superior instruments of this kind have recently been made in this country by Mr. Amasa Holcomb, of Southwick, Massachusetts.

This telescope is made like that of Newton, except that the reflection from the plane mirror is avoided by inclining the speculum, A B, figure 237, a little to one side, so that the image is formed on that side of the tube, as at E, where, of course, the eye-piece is placed. The head of the observer being at E,

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from the large speculum formed? What is the use of the small mirror? What is the design of the eye-glass? By whom was the Newtonian telescope invented? Of what does it consist? 501. In what does Herschel's telescope differ from the Newtonian? How does the observer stand when

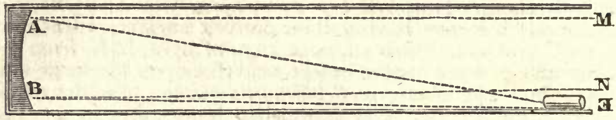

Fig. 257.

some portion of the rays, M N, are intercepted, but not as large a portion as is lost by the reflection from the plane mirror in Newton's telescope. In viewing near objects, too, especially if the instrument is very short, some distortion of the image would be produced; but nothing of this is observed when it is of considerable length and used for astronomical purposes, for which it is chiefly, if not wholly, intended. In using this instrument the observer, of course, stands with his back towards the object.

The magnificent telescope constructed by the elder Dr. Herschel has often been described. The speculum it contained was 4 feet in diameter, and had a focal length of 40 feet. The highest magnifying power of the instrument was 6450, which, however, was seldom used, a lower power being generally preferred.

Recently a still larger telescope has been constructed in Ireland, by the Earl of Rosse. The form of this telescope is the same as that of Herschel's, just described; but the great speculum is much larger, being 6 feet in diameter, and having a focal distance of 54 feet. Its thickness is 5½ inches, and its weight nearly 4 tons.

Little use has yet been made of this leviathan instrument, as it is not yet entirely finished, but the few observations made with it are said to have been very satisfactory.

CHAPTER VII.

MAGNETISM.

502. Magnetism is the science which treats of the properties and effects of the *magnet*. This is an ore of iron, pieces of which have been long known to possess the power of attracting each other, as well as pieces of iron and steel, when brought

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using this telescope? What was the diameter of the speculum in Herschel's great telescope? What was its focal distance? What is the diameter and focal distance of the leviathan telescope recently constructed by the Earl of Rosse? 502. What is magnetism? What is the *magnet*? What peculiar property does it possess?

in their vicinity. The name magnet, given to pieces of this ore, is said to be derived from Magnesia, a town in Greece, from which they were obtained.

503. This ore of iron is now found in almost every country, and is usually called *loadstone.* Sometimes pieces of it are cut into regular forms, and used as magnets. They are often called *natural magnets*, to distinguish them from artificial magnets, to be hereafter described.

If a mass of this ore of iron, of tolerably regular form, be rolled in iron filings, there will generally be found two points, and only two, nearly opposite each other, on which the filings chiefly collect; between these points few only will adhere. These points where the filings collect are called the poles of the magnet. N S, figure 238, represents a natural magnet which has thus been rolled in iron filings; N and S are the poles around which the filings chiefly collect. If the magnet be placed upon a piece of wood in a basin of water, the piece of wood—supposing it, of course, capable of floating in the water with the loadstone upon it—will turn round, whatever may be its position at first, so that one of the two poles shall be towards the north, which is therefore called the *north pole*, and the other towards the south, and is therefore called its *south pole.* Its tendency thus to arrange itself is called its *directive property*, and has been long known. Often pieces of loadstone are seen of so regular a form that they may be suspended by a cord, so as readily to place themselves in this position.

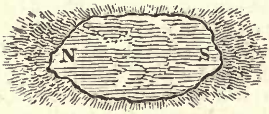

Fig. 238.

504. When two magnets made to float upon water, as described above, are brought near each other, it will be found that, when two north poles or two south poles are presented together, they repel each other, but when a north and a south pole are presented together, they attract each other. We have, therefore, this principle, that *like poles repel, but unlike poles attract each other.*

505. The natural magnet has the power of communicating its properties to pieces of steel simply by being brought, for a short time, in contact with them. They are then said to be magnetized, and are called *artificial magnets.* In examining

Quest. 503. Is this ore of iron very commonly found? What is it called? If a piece of the native magnet is rolled in iron filings, what is the result? If the magnet is placed upon a piece of wood capable of floating with it in a basin of water, in what direction does it settle? What is the *north* and what the *south* pole of the magnet? What is meant by the *directive property* of the magnet? 504. When two magnets, floating upon separate pieces of wood in a basin of water, are brought near each other, what is observed? 505. Does the natural magnet have the power of communicating its properties to pieces of steel? What are *artificial magnets?* May either

the phenomena of magnetism it is of no importance whether we use the natural or artificial magnet; but as the latter can more easily be made of any form desired, and is much less liable to be accidentally broken, it is usually preferred. The north pole of an artificial magnet usually has a line drawn across it, to distinguish it.

A small bar of steel, magnetized in the manner described, and suspended at its centre of gravity upon a pivot, so as to move freely, constitutes the *magnetic needle*. Figure 239 represents an instrument of this kind. When the needle is suspended in this manner, whatever may be its position at first as to the meridian, when left to itself, after a few oscillations it soon settles in the direction of north and south, the north pole, N, being to the north, and the south pole, S, to the south.

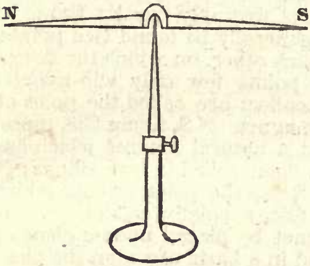

Fig. 239.

506. Two needles of this kind serve well to perform the experiment described above (§ 504) as being made with two natural magnets placed upon pieces of wood floating in water. When two similar poles are brought near together, a strong repulsion is observed; but if the poles are unlike, there will be an equally strong attraction. The repulsion or attraction is mutual, no doubt, and both the needles move more or less if they are free; but if one is held in the hand, while one of its poles is presented to the other needle, that alone, of course, can move, though the force exerted between them is mutual.

507. When pieces of iron are attracted by a magnet, they always become themselves magnetic. Let N S, figure 240, be a magnetic bar, and let a piece of soft iron, B, be presented to its south pole, S, it will be instantly attracted; and if it is examined while held in contact with the magnetic bar, it will be found that its lower end is a south pole and its upper end a north pole. If a second piece, C, be

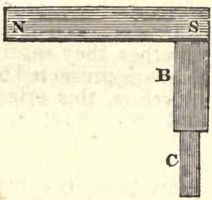

Fig. 240.

natural or artificial magnets be used in investigating the phenomena of magnetism? How is the north pole of an artificial magnet usually marked? What is the magnetic needle? When the needle, properly suspended, is left to itself, in what direction does it settle? If the two similar poles of two needles are brought near each other, what is the effect? If the poles are dissimilar, what is the effect? Is the repulsion or attraction between the needles mutual? 507. What effect is produced on a piece of iron when it is attracted by a magnet? Does the extremity of a piece of iron, in contact with one of the poles of a magnet, possess the same or the opposite polarity?

now presented to the first, it will be likewise attracted, and will become magnetic, its upper end being a north pole and its lower end a south pole, as before. Other pieces still might be attached in like manner, and each would become magnetic, but the magnetism of each successive piece will be weaker and weaker.

It will be particularly observed that the upper end of the iron bar, which becomes a north pole, is in contact with the south pole of the magnet. This is always the case; the south pole of a magnet always induces a north pole in that part of a piece of iron which is next to it, while the part farthest from it will be a south pole. So, when a piece of iron is presented to the north pole of a magnet, the part next to the magnet becomes a south pole, while the other part becomes a north pole.

508. But, though the pieces of iron are so readily magnetized, they do not retain their magnetism. This may be shown by taking hold of the piece B and removing it from the magnet; its magnetism is instantly destroyed, as will be shown by the dropping of the other pieces attached to it.

The development of magnetic properties in a piece of iron in this manner, merely by the approach of one of the poles of a magnet, is called *magnetic induction*, from its analogy to electrical induction, to be hereafter explained. Though we have supposed the iron, in the above experiment, in contact with the magnet, this is not necessary; it only requires to be brought near to it. This may be shown by holding the piece of iron at a little distance from the pole of the magnet, and then presenting to one end of the iron another small piece, which it will be found to attract, though it will cease to hold it if removed too far from the magnet. But when the piece of iron is in contact with the magnet, its magnetism is stronger.

The same thing may be familiarly illustrated as follows:—Lay a large nail upon a piece of window-glass, and place near one end of it some small tacks, or other pieces of iron; no appearance of attraction between them and the nail will be at first observed. Holding the glass in one hand, with the nail upon it and small tacks scattered upon one end, bring one pole of the magnet under the glass, near the other end of the nail; the tacks will be seen to be instantly attracted by the nail, by reason of the magnetism induced in it by the influence of the magnetic pole beneath the glass. But the nail, it will be observed, has not been in contact with the magnet, for the glass has all the time been between them.

When a piece of iron becomes magnetic by being in contact with a magnet, will it attract a second piece? 508. What is the effect of carefully removing the magnet from the first piece? What is meant by *magnetic induction?* That magnetism may be induced in a piece of iron, must it be in contact with the magnet? Is the induced magnetism strongest when the iron is in contact with the magnet? May magnetism be induced in iron through a

This leads us to remark, further, that the inductive influence is exerted through all other substances that are not themselves capable of becoming magnetic, and without any diminution of the effect. Thus the magnetism induced in a bar of iron, held at a given distance from one of the poles of a magnet, will be of the same intensity, whether a plate of glass or copper, or a piece of wood, be held between them, or whether a stratum of air only intervenes.

509. The attraction of a piece of iron by a magnet seems to be in consequence simply of the magnetism first induced in it; and the reason why other substances are not also attracted is because they are not capable of becoming magnetic.

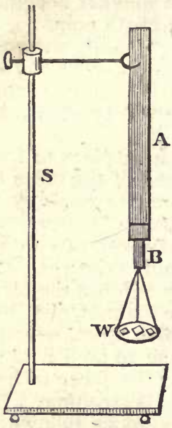

Fig. 241.

510. When a magnet acts upon a bar of iron to induce magnetism in it, its own magnetism is always, at the same time, increased by the reaction of the magnetism of the bar upon the magnet. This may be shown by direct experiment. Let A, figure 241, be a bar magnet, suspended to a common lamp-stand, S; B a small piece of soft iron, with a scale-pan and weights, W, attached by means of cords. With this it will be easy to determine the weight the magnet is capable of sustaining; and when this is done, let a bar of soft iron, about equal in size to the magnet, be held against the upper end of the magnet. If trial is now made, it will be found that more weight will be sustained by the magnet than before the iron was placed above it.

511. If the north poles or south poles of two magnets are both together brought in contact with one end of a bar of iron, the magnetism induced in it will be more intense than if one alone had been used; but the effect will be still greater if the bar of iron is placed between the two magnets, so that the north pole of one magnet shall be in contact with one extremity, and the south pole of the other magnet in contact with the other extremity. Both magnets then conspire to produce the same result, and the effect is the greatest possible.

When the north pole of a magnet is placed against the centre of a bar of iron, a complex effect is produced; the centre of it

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piece of glass? Is the inductive influence exerted through other substances? 509. Why may not other bodies besides iron and steel be attracted by the magnet? 510. When a magnet acts upon a piece of iron to induce magnetism in it, how is its own magnetism affected? How may this be shown? 511. How must two magnets be presented to a bar of iron, in order to produce the greatest inductive influence? What is the effect when the north pole of a magnet is brought in contact with the centre of an iron bar?

becomes a south pole, while the two extremities of it are both north poles, figure 242. If the south pole had been used, the middle of the bar would, of course, have been a north pole, and the two ends south poles. If the north pole of a magnet is placed on the centre of a star made of sheet iron, so as to be perpendicular to it, as is shown in figure 243, the centre becomes a south pole, and all the extremities of the rays north poles of weak intensity.

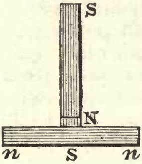

Fig. 242.

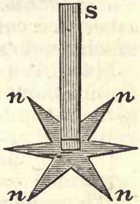

Fig. 243.

512. A curious and not uninstructive experiment may be performed with two straight magnets and a piece of soft iron, made in the form of the letter Y. Let *a b* C, figure 244, be this piece of iron, which may be suspended by one of the branches to the north pole of one of the magnets, as A. Its lower end will immediately become a north pole, and will be capable of sustaining a small piece of iron, as a key; but if, while held in this manner, the south pole of the other magnet, B, be brought in contact with the other branch, *b*, of the piece of iron, the key will instantly drop off. This is occasioned by the opposing action of the two magnets, neutralizing each other's influence. The branch *a* will have a south polarity, and the branch *b* a north polarity, while the lower extremity will be neutral.

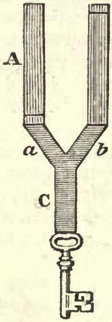

Fig. 244.

513. We have seen that though pieces of iron so readily become magnetic, under the influence of a magnet placed in their vicinity, they do not retain their magnetism after being removed from the magnet. It is otherwise with pieces of steel properly tempered; they do not become magnetic as readily as pieces of iron, but when the magnetic property is once induced in them, they retain it permanently. When one end of a piece of steel of considerable length is brought near one of the poles of a magnet, it does not instantly become magnetic through its whole extent, as a bar of iron does, but it requires a perceptible time for the magnetic influence to reach the further end. Sometimes the steel bar is divided into several parts, there being several north and south poles in succession. Let A, figure 245, be a magnet, and B a bar of steel, placed very

Fig. 245.

Quest. 512. What curious experiment is illustrated in figure 244? 513. Do pieces of steel retain their magnetism when they have been once magnetized? Is the magnetic virtue as readily induced in steel as in iron?

near its north pole, but not actually in contact with it. If the bar be now examined by means of a very short and delicate magnetic needle, it will be found to have a south pole at the end nearest the magnet, and a north pole at the other end; but between these will be other weak north and south poles, alternating with each other, as indicated by the letters *s* and *n*. These points, where the polarities thus change from one to the other, are called *consecutive points*, and their occurrence very much weakens the general magnetic power of the bar.

514. It is a remarkable fact that if a magnet be broken into two or more parts, all the pieces will instantly be found to be perfect magnets; that is, each of them will have both a north and a south pole, though the point at which they were separated was before perfectly neutral. This experiment may easily be performed by magnetizing a piece of a watch-spring, and then breaking it in the centre and examining closely the two pieces.

515. When a magnet is used for inducing magnetism in pieces of iron or steel, it loses nothing of its own power; but, on the contrary, its own magnetism is rather increased (§ 509), if it was not before at a maximum. It seems, therefore, that nothing has been given up by it to the iron or steel with which it has been used, but only a property already existing there has been waked up, as it were, or developed. It is not possible, by any means known, to obtain one kind of polarity without the other accompanying it at the same time; that is, to obtain a north pole without a south pole, or a south pole without a north pole accompanying it in the same piece.

516. We have seen above that a piece of steel may be magnetized, or an artificial magnet produced, simply by bringing one of its extremities in contact with one of the poles of another magnet; but it will be better to pass one pole of a magnet, held in an inclined position, over the whole length of the steel bar, each time moving it in the same direction, from left to right or from right to left. This is called the method of *single touch;* the design of passing the magnet over the whole bar is to prevent the formation of consecutive points.

In the method by *double touch*, as it is called, two magnets are used, one being held in each hand; and the north pole of one being brought near the south pole of the other, both together are placed on the centre of the bar, A B, to be magnetized, as represented in figure 246,

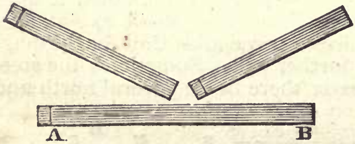

Fig. 246.

Quest. 514. If a magnet is suddenly broken into two or more pieces, will each be a perfect magnet? 515. Does a magnet lose any of its power when it is used to induce magnetism in a bar of iron or steel? Is anything communicated to the body magnetized? What is the method of magnetizing a bar of steel by single touch? What is the method of double touch? What

and then drawn towards its extremities. The magnets should always be held considerably inclined to the bar to be magnetized. This process should be repeated ten or twelve times, which will usually be sufficient to magnetize the bar to the highest point.

If a bar of steel is heated to redness, and then suddenly cooled by throwing water upon it while in contact with one of the poles of a magnet, it will usually be found to become magnetic. The magnetism is induced in the bar while in its soft state by reason of the heat, and becomes fixed when it is hardened by cooling. So a bar of steel will often become feebly magnetic simply by being hammered while lying in the direction of north and south, or by being struck several times with a hammer, so as to produce a ringing sound.

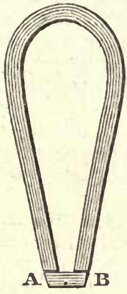

Fig. 247.

517. The poles of a bar magnet are so far apart that it is inconvenient to bring them both to act on the same object at once; artificial magnets are therefore often made somewhat in the shape of a horse-shoe, as seen in figure 247, and are called *horse-shoe magnets*. A piece of soft iron, A B, used to connect the poles, is called the *armature*, or *keeper*. One end of this being in contact with one pole of the magnet, and the other with the other pole, it will, of course, become powerfully magnetic, and will be attracted with great force. By attaching weights to the armature, by means of a cord, the magnet may in this way be made to exert the greatest power of which it is capable.

By combining several horse-shoe magnets powerful *magnetic batteries* have sometimes been constructed, of sufficient power to lift many pounds. The several magnets are placed so that all their north poles shall be in contact, and all their south poles; and, as a matter of course, they react slightly upon each other, so as to diminish their joint effect. Thus, if there are six magnets, each of which alone is capable of lifting four pounds, the six together, when combined, as in figure 248, will not lift twenty-four pounds.

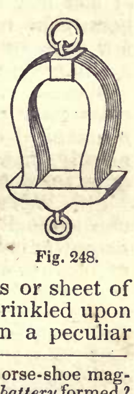
Fig. 248.

If the poles of a powerful horse-shoe magnet be placed against the under side of a pane of glass or sheet of paper held horizontally, and fine iron-filings be sprinkled upon the upper side, they will arrange themselves in a peculiar

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other method is described? 517. What is the form of the horse-shoe magnet? What is the *armature*, or *keeper?* How is the *magnetic battery* formed? Will several magnets combined in this manner produce a joint effect equal to the sum of the effects of the single magnets? What experiment is illus-

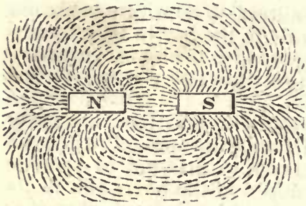

Fig. 249.

curve, as represented in figure 249. This is occasioned by the inductive influence of the two poles of the magnet, by which all the small pieces of iron are converted into magnets, which act upon each other, as already explained of other magnets. When the magnet is moved along the lower surface of the glass a peculiar movement is produced among the iron-filings, not unlike that of a multitude of small animals.

518. All magnets, if left to themselves, gradually suffer a diminution of their magnetism, and, in process of time, even lose it entirely; but natural magnets retain it much longer than artificial ones. But by suitable precautions they may be preserved for any length of time, and their power even increased. Two magnets, kept with their similar poles together, injure each other very much, and if nearly of equal power, may destroy each other in a short time: if one is much stronger than the other, the weaker will be likely to have its polarity reversed; that is, its north pole will become a south pole, and its south pole a north pole.

It is found that magnets are best preserved when kept constantly in exercise. This is accomplished by bringing the unlike poles of two magnets together, as by placing two bar magnets of equal length side by side, or by extending a piece of soft iron from one pole to the other. The power of the horse-shoe magnet will often be considerably increased, in a few days, by suspending from its armature as much weight as it will bear, and adding to it from time to time.

Magnets should always be kept free from rust, which impairs their power; and they should also be protected from mechanical injury. The power of a magnet has often been greatly impaired by a single blow, or by a fall upon the floor or pavement.

519. When a magnet is heated to redness and allowed to cool again, its magnetism is invariably entirely destroyed; and its power is impaired by even so small a degree of heat as that of boiling water. On the other hand, at very low temperatures the power is increased.

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trated in figure 249? 518. Does the power of a magnet diminish by keeping? What precaution may be taken to prevent this effect? How may the power of a magnet be increased by keeping? What is said of the effect of a blow upon a magnet, or of letting it fall upon the pavement? What is said of the effect of rust upon a magnet? 519. How is the magnet affected by heat? How by cold?

520. It is believed that nearly all substances are capable of exhibiting a feeble magnetism when under the inductive influence of a powerful magnet; but two only, (besides iron or some of its compounds,) the metals nickel and cobalt, retain it; and the magnetism of these, at best, is very weak.

521. *Terrestrial Magnetism.*—We have seen that when a natural or artificial magnet is suspended so as to move freely, it will, when it comes to a state of rest, present one of its poles to the north and the other to the south. This is, no doubt, produced by the influence of the earth acting as an immense but distant magnet upon the needle. Indeed, in order to understand clearly all the various relations of the magnetic needle to the earth, we may with propriety consider the latter as a great magnet, having one of its poles at or near the north pole of the earth, and the other pole near its south pole. But we have concluded to call that pole of the needle which points to the north the north pole, and the other the south pole (§ 503); and as unlike poles attract while like poles repel each other, it follows, as a matter of course, that the magnetic pole at or near the north pole of the earth must be a *south* pole, or possess southern polarity, while that in the southern hemisphere must possess *north* polarity.

522. If a piece of steel, made in the form of the magnetic needle, is accurately balanced upon a pivot, so as to remain in a horizontal position, after being magnetized the north pole will dip or be depressed considerably below its former horizontal position. This is, no doubt, occasioned by the influence of the earth's magnetism, which is exerted more on the north pole than on the south pole, so that the north pole is drawn downward. This is not surprising, since we are situated so much nearer the north than the south pole of the earth. Let A B, figure 250, be a bar magnet lying horizontally upon the table, and then let a small magnet, suspended by a thread, so as to hang horizontally, be held at D, over the centre of the large magnet; its north pole

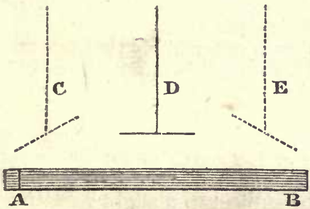

Fig. 250.

Quest. 520. Is it supposed that nearly all substances are capable of exhibiting slight traces of magnetism when under the influence of a powerful magnet? What two only, besides iron and its compounds, retain the magnetism? 521. What is it that occasions the magnetic needle to settle in a north and south direction? May we consider the earth to act as a great magnet upon magnetized bodies at its surface? What kind of polarity must its pole in the northern hemisphere possess? How does this appear? 522. If a piece of steel is accurately balanced upon a pivot, and then magnetized, what effect is observed? How is this accounted for? How is it illustrated in figure 250?

will point towards B and its south pole towards A; both of its poles being equally acted upon by the poles of the large magnet, it will remain in its horizontal position, as shown in the figure. But let it next be carried gradually towards the north pole, A, of the magnet; the south pole of the small needle will immediately begin to dip, and the dip will increase as it approaches the pole A. So, if the needle is moved towards the other pole of the magnetic bar, the other pole will be depressed in the same manner. The position it would take at C and E is shown in the figure.

523. A needle prepared expressly for showing the dip or variation from a horizontal position is called a *dipping-needle.* Figure 251 represents the simplest form of this instrument. A B is a flat piece of wood, for a base, provided with a spirit-level and screw, for leveling it with great accuracy; and to it is attached a graduated circle of metal, C C, having on each side of it a horizontal bar, H H, to support the needle, N S, so that it revolves freely in a vertical circle between them. As the parts of the needle are made to balance each other very accurately before it is magnetized, the position it takes after becoming a magnet will depend upon the magnetic attraction of the earth.

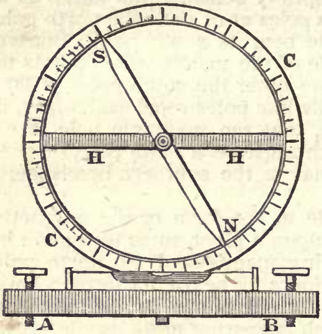

Fig. 251.

524. By this instrument it has been determined that near the equator the needle is horizontal; but as it is carried north the north pole begins to dip, while at the south of the equator the south pole of the needle dips. Towards the polar regions, either in the northern or southern hemisphere, the dip becomes very great; and if the true pole of the earth could be found, the needle would there stand perpendicularly. The dip of the needle at any place is found to be subject to a slight variation; but in London, in 1830, it was 69° 38′; at Paris, in 1835, it was 67° 24′. The dip, at the present time, is,

At Baltimore,	about.............	71° 30′
" Philadelphia,	"	72 15
" New York,	"	73 0
" Middletown, Ct.,	"	73 30
" Boston,	"	74 24

Quest. 523. What is the *dipping-needle?* 524. What is the dip at the equator? What is the effect if the needle is removed to the north or south of the equator? What is the amount of the dip, at the present time, at Baltimore, New York, and Boston?

525. We have said that near the equator there is no dip; the places where this occurs are situated in a line that encircles the earth, and is called the *magnetic equator*. It deviates much from the geographical equator, being sometimes north and sometimes south of it, and, of course, crossing it several times.

526. It has been stated, also, that the magnetic needle, when properly suspended, and uninfluenced by any other magnetized body, will settle in the general direction of north and south; but it is now well known that it is subject to deviate more or less to the east or west of this position. This deviation of the needle from the true meridian is called its *declination*, or *variation*, and sometimes amounts to many degrees.

The direction in which the needle settles in any place is called the *magnetic meridian* of the place; and the angle between this and the true meridian is, of course, the variation.

The variation at any place is constantly changing: at London, about 265 years ago, it was 11° 15′ east; that is, the north pole of the needle deviated 11 degrees 15 minutes to the east of the true north; but it gradually diminished, so that, in 80 years afterwards, or about the year 1660, it became nothing, and the needle pointed to the true north. Immediately afterwards a western declination commenced, which gradually and uniformly increased until 1815, when it amounted to 24° 27′: since that time it seems to have been diminishing, and in 1840 was said to be less than 24 degrees. At Philadelphia the variation in 1840 was about 3° 52′ west; at New York about 5° 23′; at New Haven, Ct., about 6° 0′; at Middletown, Ct., about 6° 40′, and at Boston about 8° 55′. The variation at all these places, it is believed, is now diminishing. The *line of no variation* is an irregular circle, passing round the earth from north to south; in this country, at the present time, it passes through lake Huron and lake Erie, a little west of the western line of Pennsylvania, crosses the south-west corner of that state, and the states of Virginia and North Carolina, entering the Atlantic ocean a little east of the line between North and South Carolina. This line of no variation is by no means fixed, but is constantly varying, sometimes moving gradually east for a series of years, and then again changing its motion to the west. East of this line, for a considerable distance, the variation is west, but west of it the variation is east; and on both sides it is greater the farther the distance, within certain limits, from the line.

Quest. 525. What is the *magnetic equator?* Does it deviate from the geographical equator? 526. Does the needle always point to the true north and south? What is meant by the *declination* or *variation* of the needle? What is the *magnetic meridian* of a place? Is the declination at any place always the same? What changes have taken place in the declination at London in the last 265 years? What is the present declination at New York? What is meant by the *line of no variation?* Through what parts of this country does this line pass? What is said of the variation east and west of this line?

527. Both the declination and the dip of the magnetic needle are subject to a variation according to the season of the year and the hour of the day. In this country the declination of the needle from the true north is greater in the middle of the day than in the night; and this diurnal change is greater in the warm months of summer than in the winter.

528. We are now prepared to investigate a little more particularly the relation of the earth, considered as a great magnet, and small magnets at any place upon its surface. In the northern hemisphere, especially in high latitudes, the pole near the north geographical pole of the earth is much nearer to us than the other magnetic pole, and it is its influence, therefore, which is chiefly to be noted. But this pole of the earth is a south pole—as we have seen (§ 521)—that is, it possesses southern polarity, and therefore it draws towards it the north pole of the needle.

But, if the earth may with propriety be considered an immense magnet, acting like other magnets, we may, of course, expect it to have an inductive influence, as well as other magnets, on masses of iron and steel. And this is found to be the case. Bars of steel that have stood long in a perpendicular position, and even bars of common iron, are often found to have acquired a feeble degree of magnetism, the lower end being a north and the upper end a south pole. Tongs and pokers, from their having some degree of hardness, and their being almost always kept nearly perpendicular, are generally magnetic, as will be seen by presenting the lower extremity very cautiously to the north pole of a needle, or the upper end to the south pole. In either case slight repulsion will be produced, which indicates the presence of similar poles. The blade of a penknife may often be magnetized by a pair of tongs, or a poker, so as to be capable of lifting a large sewing-needle.

529. The inductive influence of the earth's magnetism may, therefore, be made use of to obtain permanent magnetism, in the absence of all other magnetized bodies. This is best accomplished as follows:—Let the small piece of steel to be magnetized be suspended by threads to the edge of a table, in a north and south position, and then let two long bars of iron, as two pokers, be held, one above it and the other below it, at

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Quest. 527. Do both the variation and dip of the needle have a daily change? 528. Which of the poles of the earth is nearest to us? If the earth may be considered as a great magnet, should we expect it to exert an inductive influence upon masses of iron or steel upon its surface? What effect is produced upon bars of steel that have stood long in a perpendicular position? Which extremity is a north pole? How is this accounted for? Why are tongs and pokers usually found to be magnetic? How may they be made to magnetize the blade of a penknife? 529. How may the inductive influence of the earth's magnetism be made use of to obtain permanent mag-

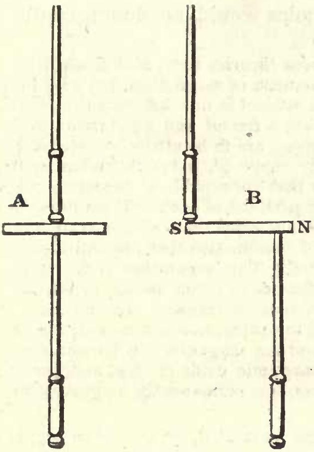

Fig. 252.

its centre, as is shown in A, figure 252. The upper bar is now to be carried to the south, and the lower bar to the north, as shown in B, both being kept in a vertical position; after repeating this several times, the piece of steel will generally be found to be fully magnetized. After what has been said, any further explanation is hardly necessary. The bars of iron, by the inductive influence of earth, become magnetic, their lower ends being north poles (§ 521), and, by using two at the same time, in the manner described, the effect is much increased. By placing the piece of steel to be magnetized in a north and south direction, the direct inductive influence of the earth upon it favours the action of the iron bars.

530. The *compass* is an instrument fitted up with a magnetic needle and a graduated circle of metal, or a circular card, for the purpose of measuring the angles any objects make with the meridian. The *mariner's* compass usually has the needle attached to a circular card, which is suspended upon a pivot, and turns freely. When great accuracy is required, it is evident, allowance must be made for the declination of the needle at the place; this is especially important for seamen, whose only guide across the pathless ocean is the faithful needle. So, also, local attractions often produce great derangement, as the vicinity of masses of iron, or iron mines, which must always be guarded against. The iron used in the construction of ships often produces a considerable derangement of the needle, and means have been devised to apply the necessary correction; but the subject is too complicated to be here introduced.

531. As the natural magnet, or loadstone, is only an oxide of iron possessing the magnetic property, it is evident this property has been communicated to it by the inductive influence of the earth; and if masses of it were examined as they lie in

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netism? What is the explanation of this process? 530. What is the *compass?* How is the *mariner's* compass usually constructed? In the use of the compass must allowance always be made for the variation of the needle? Do local attractions sometimes affect the action of the compass? What is said of the action of the iron used in the construction of ships upon the compass? 531. How are we to suppose the magnetic virtue has been communicated to the masses of iron ore existing in the earth?

the earth, the situation of the poles would, no doubt, confirm this remark.

532. *Theories of Magnetism.*—Various theories have, at different times, been proposed to account for the phenomena of magnetism, but with little success. So far as any theory on the subject is now adopted, that which supposes there are two magnetic fluids, a *Boreal* and an *Austral*, to the agency of which all magnetic phenomena are to be attributed, seems generally to prevail. These fluids, it is supposed, naturally reside in the particles of iron and other substances that are capable of becoming magnetic, in a state of combination. The particles of each of these fluids are supposed to attract those of the other, but repel those of the same kind. When these two fluids are in a state of combination they are entirely neutral, but become active when separated. This separation of the united fluids is produced by the inductive influence of either the one or the other acting alone, constituting the pole of another magnet. In soft iron, as soon as the influence which produced the separation is removed, the particles of the two fluids again unite, and the magnetic phenomena disappear; but in hardened steel and the magnetic oxide of iron, and, indeed, in all other substances which may become permanently magnetic, they are supposed to remain separate.

533. But, though these fluids are thus separated, we are not to suppose that they are ever transported from one body to another, or even from one part to another of the same piece of iron or steel. We have heretofore seen (§ 514) that when a bar magnet is broken into two pieces, in the centre, we do not have a north pole in one and a south pole in the other, as would be the case if the two fluids were separated in the opposite extremities of the bar, but each piece is found to be a perfect magnet, having both a north and a south pole, precisely like the bar before it was broken. We must therefore suppose the two fluids are never separated from the particle to which they belong, but are only removed to opposite sides of the particle, as shown in figure 253. Let S N be a bar magnet consisting of two rows of particles, the *austral* fluid will all be collected on the sides of the particles towards N, as shown by the letter *n*, and the *boreal* on the sides next to S, as shown by the letter *s*. The effect of thus separating the two fluids, in connection with the particles of a piece of iron or steel, is to develop in it the ordinary properties of magnetism.

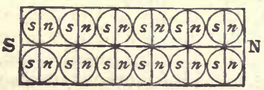

Fig. 253.

534. It is known that in the centre of a magnet, that is, at a point equally distant from the two extremities, there is no attractive influence; but at a little distance from this point, towards either end, it begins to appear, and increases quite to the ends called the poles. The reason of this is evident, if our theory is true, for, except the extreme particles, each north pole is always in contact with a south pole, and of course the two should neutralize each other, so that the attractive influence is exerted only by the extreme particles, and extends to a certain distance from them in every direction. The influence of each pole will therefore be neutralized at the central point between them.

For a full discussion of the intimate relation between this branch of science and that of electricity, see author's Chemistry.

CHAPTER VIII.

ELECTRICITY.

535. If a glass rod, or tube, that has remained untouched for some time, be held near a feather or other light body, suspended by a fine silk thread, nothing special is observed, though the glass be presented so near as to touch it, and then withdrawn; the feather maintains its position undisturbed. But let the glass tube be made dry and warm, and then rubbed briskly for a few seconds with a woollen cloth or a silk handkerchief; upon holding it near the feather now it is at once disturbed, even when the tube is at some distance, and manifestly tends to approach it; and when the tube is brought sufficiently near, it suddenly darts to it, usually adhering for a moment, when it is repelled with equal force.

536. It is evident that, by means of the friction with the cloth or handkerchief, a property has been imparted to the glass which it did not before possess, and by virtue of which it exerts an attraction upon the feather. But this property is not peculiar to glass; pieces of resin, sealing-wax, amber, sulphur, &c., when rubbed in a similar manner, possess the same power of attracting other light bodies.

The physical agent, whatever its nature may be, which is thus called into operation, in these and other substances, by friction, and to which the attractions are to be attributed, is called *Electricity*. This name is derived from *electron*, the Greek name for amber, the first substance which was observed to exhibit the phenomena of attraction just described. The first observations on the subject that are on record were made by Thales, about 600 years before the birth of Christ.

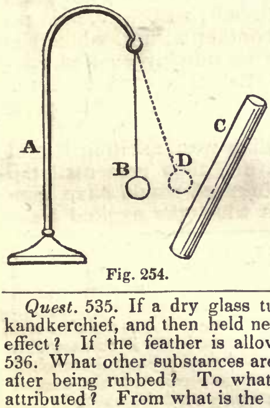

Fig. 254.

537. To examine the various circumstances attending the phenomena above described, let a glass tube an inch in diameter and two feet long be provided, and also a stick of sealing-wax an inch in diameter and 12 or 14 inches long, and a pith-ball electrometer, figure 254.

Quest. 535. If a dry glass tube is rubbed with a woollen cloth or silk kandkerchief, and then held near a feather or other light body, what is the effect? If the feather is allowed to touch the tube, what is the result? 536. What other substances are mentioned as possessing the same property after being rubbed? To what agent are these attractions and repulsions attributed? From what is the name electricity derived? 537. What three pieces of apparatus are recommended for pursuing our investigation in this

This *electrometer*, or measurer of electricity, consists of a glass rod, A, fixed in a stand, and bent at top, so that a ball, B, made of the pith of the elder, may be suspended from it by a thread of silk. On rubbing the tube or sealing-wax with a warm and dry woollen cloth or silk handkerchief, and presenting it near the pith-ball, as at C, the ball is strongly attracted towards it, as to D, and, if not allowed to touch the tube, remains there until the glass or sealing-wax is moved.

When a body is capable of producing this effect, it is said to be *excited*, and the result with the pith-ball is the same whether an excited glass tube be used or an excited stick of sealing-wax, provided the ball is not allowed to come in contact with it.

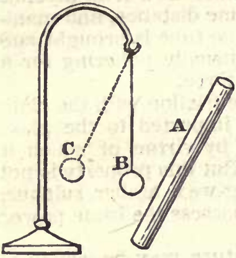

Fig. 255.

When using the excited glass tube, A, figure 255, if the pith-ball, B, is allowed to touch it, it at once flies off, as to C, and remains there until the tube is removed, constantly manifesting a strong repulsion for it. If the finger is now touched to the ball, and then the same experiment repeated with the stick of sealing-wax, the results will be precisely the same; the pith-ball will at first be attracted, but after contact it will be as strongly repelled.

538. Thus far, then, we have observed no difference between the action of the glass tube and that of the sealing-wax; both seem to have the same properties, both attracting the pith-ball, and then, after contact, repelling it. But, having excited the glass tube, let us now present it to the pith-ball; as before, it is attracted to the glass until coming in contact with it, when it is repelled. Next, let the sealing-wax be quickly excited, and presented to the pith-ball; a strong attraction ensues: but if the sealing-wax is removed, and the tube again presented, it is repelled as before.

If we had commenced with the sealing-wax, exciting it and bringing it in contact with the ball, and then presented the excited glass tube, the phenomena observed would have been the same; and we therefore find that when the excited glass

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subject? What is an *electrometer?* When is a body said to be *excited?* If the pith-ball is not allowed to touch the glass or sealing-wax, will the result be the same with both? If the pith-ball is allowed to touch the excited tube, what will be the effect? 538. So far as we have now pursued our investigation, has any difference been observed between the action of the tube and that of the sealing-wax? But if we bring the excited tube in contact with the pith-ball, so as to cause it to be repelled, and then present the excited sealing-wax, what is the effect? If we had commenced with the excited sealing-wax, touching the ball with it, and then presented the excited tube, would the result have been the same? If two pith-balls are suspended from

tube attracts the pith-ball, the excited sealing-wax repels it; and when the sealing-wax repels, the glass attracts.

If, now, two pith-balls be suspended from the same support by silk threads, so as to rest in contact, when the excited glass tube is brought near they will be attracted, as before, and then repelled; but when the tube is withdrawn it will be found they no longer fall into the vertical position; but, on the contrary, they repel each other, causing the threads by which they are suspended to diverge, as A and B, figure 256. If the stick of sealing-wax had been used, the same effect would have been produced.

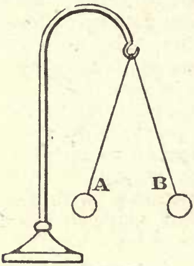

Fig. 256.

539. By the above experiments the following facts, it would seem, may be considered as settled:—

1. By the friction of the dry woollen cloth or silk handkerchief a quality is imparted to the glass and the sealing-wax, by virtue of which they become capable of exerting an attraction on the suspended pith-ball.

2. After coming in contact with the excited glass or wax the state of the ball is changed, so that, instead of being attracted by the glass or wax it has just touched, it is repelled.

3. When the pith-ball has once been in contact with the excited glass, and is repelled by it, it will be attracted by the excited wax; so, also, after it has been in contact with the excited wax, and is repelled by it, it will be attracted by the excited glass.

4. When two pith-balls have been brought in contact, either with the excited glass or sealing-wax, so as to be repelled by it, they also repel each other.

540. To account for these phenomena, and explain them, the two following theories have been proposed:—

The theory first proposed is that usually ascribed to Dufay, and therefore called Dufay's theory; the other was proposed by Franklin, and is therefore called Franklin's theory.

541. The theory of Dufay supposes that all bodies in nature, in their natural state, always have in combination with their particles two fluids, which, however, so attract and neutralize each other, as to be entirely concealed. It supposes, also, that though each fluid strongly attracts the other, yet the particles of the same fluid are mutually repulsive, and tend to diffuse themselves when unobstructed. When the two fluids are in

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the same support, and then touched with the excited tube or sealing-wax, what will be the effect? 539. What are some of the conclusions arrived at by the preceding experiments? 540. What two theories have been proposed to account for the phenomena of electricity? 541. How many fluids does the theory of Dufay suppose all bodies to have in combination with them in their natural state? What is supposed to be the state of a body, on

a state of combination in a body, no indications of either are perceived; but when, by any means, they are separated, and either of them accumulated in a body, that body is said to be excited, and exhibits the various phenomena of electricity which have been described.

One of the most common means of separating the two fluids is by friction, as above described, when one or the other of them accumulates in the body which is rubbed, and there manifests its peculiar properties. That fluid which usually collects on glass and other vitreous substances by friction is called the *vitreous fluid*, while that which is developed on sealing-wax and other resinous substances is called the *resinous fluid*.

542. The other theory, that of Franklin, supposes that there is in nature a single electric fluid only, the particles of which repel each other, but attract and are attracted by all other bodies. It supposes that all bodies, in their natural state, in which they exhibit no signs of electricity, contain a portion of this fluid, called their *natural share;* and that, when they are excited, they are made to contain either more or less than their natural share. When a piece of glass is rubbed, a portion of this fluid is supposed to pass from the substance used as a rubber to the glass, which, therefore, is made to contain more than its natural share, and is said to be *positively electrified*. On the other hand, when a stick of sealing-wax, or other resinous substance, is rubbed, a portion of the fluid contained in it is supposed to escape to the rubber, leaving in the wax, of course, less than its natural share; and it is therefore said to be *negatively electrified.*

543. It will be seen, therefore, that the positive electricity of Franklin's theory corresponds to the *vitreous* of Dufay's theory, and the *negative* of the former to the *resinous* of the latter.

Dufay's theory of two fluids is now more generally received than that of Franklin, though the terms positive and negative are universally used to designate the two fluids, in preference to the terms vitreous and resinous. But though Dufay's theory is now most generally received, there are those who believe that all electrical phenomena may equally as well be explained by that of Franklin.

544. By referring now to the experiments above described (§ 537) it will be seen that when two substances are similarly electrified—that is, when they are both excited either positively

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this theory, when it is excited? What is the fluid called which usually collects upon glass when it is rubbed? What is the other called, which collects upon sealing-wax by friction? 542. How many fluids does Franklin's theory suppose to be contained in bodies in their natural state? When a piece of glass is rubbed, what is supposed to be the effect on this fluid? What is the effect of friction on sealing-wax? What terms are used to indicate the state of the glass and of the sealing-wax after being excited? 543. What terms in the two theories correspond in meaning? Which of these theories is now most generally received? 544. When do two bodies attract

or negatively—they repel each other; but when oppositely electrified—that is, when one is positive and the other negative—they attract each other.

545. By experiment it is found that while electricity passes freely over some bodies, it refuses to pass over others, or passes over them with difficulty. The former are called *conductors* and the latter *non-conductors*.

The metals are usually considered the best conductors; and after these we may reckon charcoal, solution of salt, water, and living animals.

The following are some of the most important non-conductors, viz:—gum lac, amber, sealing-wax, sulphur, glass, silk, feathers, dry air, baked wood, and oils.

Though many experiments have been made to determine why some bodies conduct electricity while others will not, yet it still remains entirely unknown. All we can say with regard to this property of bodies is, that such is their nature.

546. When a body is surrounded entirely by non-conductors it is said to be *insulated*. Usually this is accomplished by supporting the body, whatever it is, upon glass pillars, or suspending it by threads of silk. As the air, when dry, is a non-conductor, a very little only of the fluid will be conveyed away by it; but when it is saturated with moisture, as it usually is in warm weather, it becomes a tolerably good conductor, and conveys the fluid away rapidly; so that electrical experiments, at such times, succeed only with great difficulty.

547. If we again refer to the bodies which were used in performing the experiments with the pith-balls (§ 536—539), it will be seen they are all non-conductors; and but for this property the fluid, as it was excited, would have been conveyed away to the earth, and failed to make itself manifest in the manner we have seen. Hence it is that only non-conductors usually become electrical by friction; but conductors may also be excited by friction, provided they are first insulated. Thus, if a piece of iron, which is a conductor, be supported on glass pillars, in a dry atmosphere, and struck several times with a cat's skin, it will be found to be feebly excited.

548. When an excited body is held in a dark place—or, better, when a body, as a glass tube, is excited in a dark room—faint flashes of light will be seen upon its surface, accompanied by a crackling noise. If the body is perfectly electrified, as

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and when do they repel each other? 545. Will electricity pass with equal facility over the surfaces of all bodies? Into what two classes are bodies divided in reference to their conducting power? What are some of the best conductors? What are some of the principal non-conductors? 546. When is a body said to be insulated? How is this usually accomplished? Why do electrical experiments succeed only with difficulty in a moist atmosphere? 547. Why do non-conducting substances only usually become excited by friction? How may a piece of iron, which is a conductor, be excited? 548. What is observed when a glass tube is excited in a dark room? If a pointed

when the glass tube is used, and a pointed wire or needle be presented to it, a bright spark will be seen upon its point, as represented at B, figure 257. If the body is negatively electrified, and a pointed wire be presented to it, a luminous brush will appear on its point, as shown on A. In the first case we may suppose the positive fluid to be passing on at the point, or the negative fluid to be passing off, for the effect is the same; so, in the second case, when the brush of light appears, we may consider the positive fluid as passing off from the point, or the negative fluid as passing on, the result being the same.

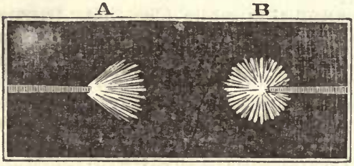

Fig. 257.

Electricity cannot be long preserved on a body, even when well insulated, if there are any points projecting from it, as the fluid passes freely and silently from points into the air, and is lost. Nor can the fluid be retained on an insulated body if there are points of other inducting bodies near turned towards it. The fluid will escape rapidly to these points, and be conveyed away.

549. Though we have spoken of glass as always becoming positively excited by friction, and sealing-wax always becoming negative, yet this is not strictly the case. It is found that when two bodies are rubbed together, both electricities are always excited in an equal degree, one of them passing to one of the substances and the other to the other. This may be proved experimentally by standing on a stool with glass legs, called an insulating stool, or on a cake of beeswax, when the glass tube is excited; the tube then becomes positive, and the person and rubber negative. To show that the person himself becomes negative by exciting the glass, let him, while standing on the insulating stool, present his hand near a suspended pith-ball, previously made negative by touching it with the excited sealing-wax. As both the ball and the hand will then be negative, the ball will, of course, be repelled.

An insulating stand, used for this purpose, is represented in figure 258; it con-

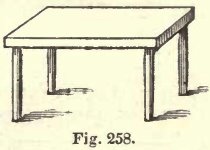
Fig. 258.

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conductor is presented to a body positively excited, what is the appearance? What if held near a body negatively excited? Why cannot electricity be retained in insulated bodies which have points projecting from them? What will be the effect of points directed towards an excited body in its vicinity? 549. Will glass *always* be positively excited by friction? When two substances are rubbed together, are both electricities always excited? How may this be proved experimentally? What will be the electrical state of the rubber and the person holding it? How is the insulating stand formed?

sists of a piece of strong plank, of suitable size, with strong glass pillars for legs, which are usually coated with varnish.

When smooth glass is rubbed by any substance except cats' fur, it becomes positive, and the rubber negative; but if it is rubbed with this substance, the glass becomes negative and the fur positive. Sealing-wax becomes negative when rubbed by any substance except a piece of rough glass or sulphur, both of which communicate to it the positive electricity. When paper and sealing-wax are rubbed together, the paper becomes positive and the wax negative; but when paper and smooth glass are rubbed together, the positive fluid goes to the glass and the negative to the paper.

550. *The Electrical Machine.* — By rubbing a glass tube or a stick of sealing-wax a number of times, and then passing it over an insulated conducting substance, so as to touch it, as a ball of metal supported on a glass pillar, a considerable quantity of electricity may be collected; but the process is necessarily tedious. To accomplish the same object more readily and conveniently, the *electrical machine* has been invented; the essential parts of which are a glass *cylinder* or *plate*, capable of being turned by the hand; a *rubber*, usually made of leather or silk, and placed so as to press against the cylinder or plate; and a *prime conductor*, to receive the electricity as it is generated. It is made of metal, and supported by a glass pillar.

A figure representing a cylindrical machine will be found in the author's Chemistry, page 75. Figure 259 represents a beautiful double plate machine, belonging to the Wesleyan University. It was made by Pixii, of Paris. A B is a firm base of wood, well framed together, and mounted on castors; P P are two circular glass plates, each 36 inches in diameter, placed on the same axis, so as to be turned at the same time by the handle, H; and to each plate are four rubbers, R R R, &c., placed at the top and bottom in pairs, one at each place, pressing against the plate on each side. From each rubber a flap of oiled silk, F, extends a distance, to prevent the electricity from being dissipated before reaching the prime conductor. C C C C is the prime conductor, made of sheet brass, and supported by four strong glass pillars; it receives the electricity from the plates by points which project from it towards them on both sides, some of which are seen in the figure.

What substance, by friction, renders glass negative? What substances, by friction with sealing-wax, renders it positive? What is said of the effect produced by rubbing together paper and sealing-wax, and paper and glass? 550. How may an insulated conductor be electrified by means of a glass tube or stick of sealing-wax? What is the design of the *electrical machine*? What are its essential parts? What is the use of the glass cylinder or plate? Of the rubber? Of the prime conductor? What is the rubber made of? How is the electricity received upon the prime conductor?

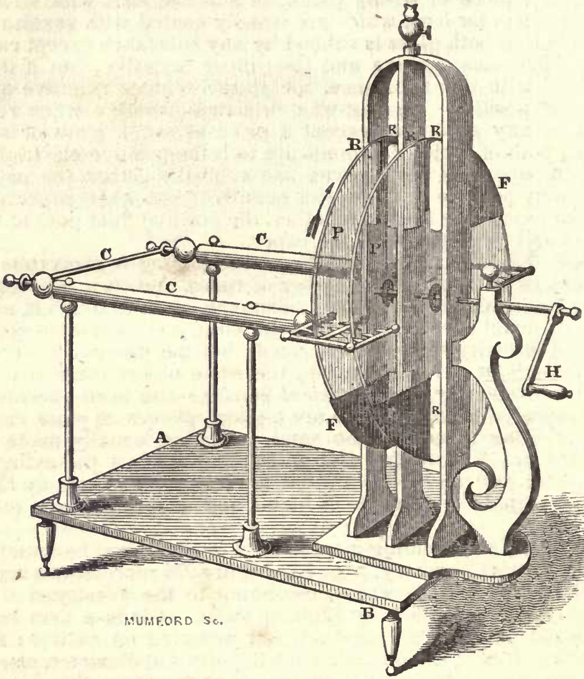

Fig. 259.

551. To increase the effect of the electrical machine, the surface of the rubber is usually spread over with an amalgam, made by melting together an ounce of tin and 3 ounces of zinc, and then pouring in two or three ounces of mercury previously heated. When cold it is to be ground to a fine powder in a mortar, and mixed with a sufficient quantity of lard or tallow to make it adhere well to the leather or silk of the rubber.

In order that electricity may be freely developed by the machine, the rubbers must not be insulated, as, in this case, while the prime conductor becomes positively electrified, the negative fluid accumulates in the rubbers, and, after a few turns of the plates, little further effect can be produced. But if the rubbers are uninsulated, the negative fluid passes off freely to

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Quest. 551. What is the use of the amalgam spread upon the rubber? What is it made of? Should the rubber be insulated when the machine is used?

the earth, while a constant supply of the positive is afforded for the prime conductor.

When the machine is to be used it should be placed so near a fire as to be slightly warmed, and every part made perfectly dry. It should also be made perfectly clean, and even the dust should be carefully wiped from every part.

By means of the electrical machine the preceding experiments are readily performed, as well as others to be hereafter described.

552. *Various Experiments.*—When electricity is passing freely over conducting substances, no indications of it are seen; it passes silently along, and mingles with that in the great reservoir, the earth. But when its passage is interrupted by a non-conductor, if its intensity is sufficient, it darts across or through the non-conductor, presenting the appearance, in the dark, of a bright spark, and attended with a smart report, depending upon the size of the spark, and the resistance it had to overcome.

The spark will be seen by presenting the knuckle near the prime conductor of the electrical machine, as it is worked; and at the same time a slight stinging sensation will be produced on the knuckle. The spark will be seen better if, instead of the knuckle, a metallic ball, on the end of a piece of wire held in the hand, is presented to the conductor. The size of the spark, and the distance through which it will strike, will depend on the intensity of the fluid collected in the prime conductor, and also upon the diameter of the ball presented to it. The colour of the spark will vary, being sometimes red, then purple, or white or bluish. It seldom passes in a straight line, but makes a zigzag course.

The human body is a good conductor of electricity; and if a person places himself upon an insulating stool, and holds in his hand a chain connecting with the prime conductor, as the machine is turned the electricity will accumulate in every part, so that a spark may be drawn from his hands, feet, or face, in the same manner as from the prime conductor.

If the person upon the insulating stand holds a metallic spoon filled with ether, in his hand, and another standing upon the floor presents a metallic knob, so as to draw a spark from the liquid, it will usually be inflamed.

When the electric spark is made to pass through a chain, the links of which are short, in a dark room, it appears lumi-

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Quest. 552. Are any signs of electricity manifested when the fluid passes freely over good conductors? What is the appearance when it darts over non-conductors? How may the spark be obtained from the prime conductor? What is the sensation produced? What is said of the colour of the spark? How may the spark be received from the face or hands of a person? How may ether be inflamed by the spark? What will be the

nous through its whole length by the spark passing from link to link.

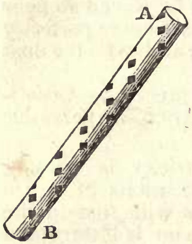

Fig. 260.

Let AB, figure 260, be a glass tube, an inch in diameter and 2 feet long, having a spiral formed on it from end to end, by pasting on small pieces of tin-foil, so as to be at a little distance from each other. If, while the machine is turned, one end of this is held in the hand, and the other presented to the prime conductor, the electric spark will dart from piece to piece of the tin-foil, producing a train of light over the spiral through the whole length of the tube. The light will, of course, be seen best in a dark room.

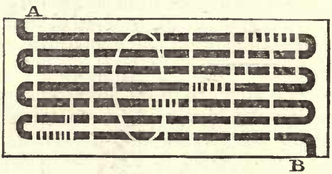

Fig. 261.

Let a plate of glass, figure 261, have a very narrow strip of tin-foil pasted on it, commencing at A and, after going several times backward and forward, terminating at B; then let several letters be formed by removing portions of the tinfoil, as LIGHT, and when the electric spark is made to pass over the foil from A to B, the word *light* will be seen written in letters of fire.

553. As the fluid escapes from a point of a conducting substance, it tends to produce motion in the point in the opposite direction. Let ABCD, figure 262, be a cross made of metal, the points of all the wires being bent at right angles in the same direction; and let it be supported at the centre upon a point fixed in the prime conductor, E, of the electrical machine. When the machine is worked, the fluid escaping from the metallic points will cause the cross to revolve rapidly in the direction shown by the arrows, exhibiting, in the dark, a complete circle of light, as it escapes from the points.

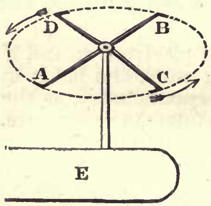

Fig. 262.

The experiment may be modified in the following manner, which shows the mechanical force that is exerted. Let T, figure 263, be a stand of wood, with four pillars of glass fixed in it, supporting the inclined metallic wires, AB and CD; and let GHIM be the metallic cross, having a horizontal axis, EF, also of metal, resting upon the inclined wires. Let a chain

appearance in the dark if the spark is received upon a tube on which a spiral of pieces of tin-foil has been formed? 553. How may motion be produced

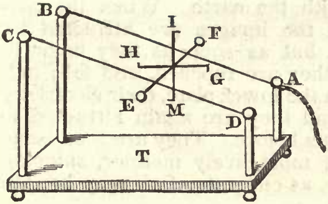

Fig. 263.

now connect one of the inclined wires, as A, with the prime conductor of the machine; and as it is turned, and the fluid escapes from the points of the cross, as before, the recoil causes it to revolve around the axis, EF, with sufficient force to roll up the inclined plane.

The *electrical orrery* is a very beautiful toy, constructed so as to revolve on the same principle, by the escape of the electric fluid from points. Let S, figure 264, represent the sun, E the earth, and M the moon, the several bodies being made of such a weight, respectively, that S, when suspended on a wire, W, as in the figure, may just balance both E and M, and E just balance M; the end of the wire, W, being bent upwards, so as to serve for a pivot to support E and M. The three bodies, thus arranged, are supported on an insulating stand, the metallic point, A, being attached to a cap which is cemented upon a glass pillar. A metallic chain connects A with the prime conductor of an electrical machine, and at P is a metallic point, and also in M, from which the electric fluid escapes, causing M to revolve around E, and both M and E to revolve around S. More properly, S and the other two bodies, considered as one, revolve around their common centre of gravity, as M and E do, also, around their centre of gravity; which, in fact, is what really takes place among the bodies of the solar system here represented.

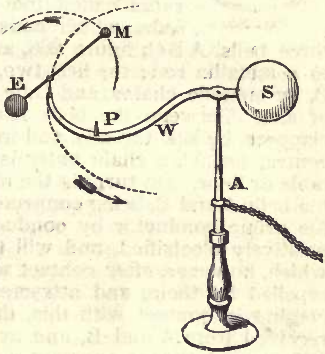

Fig. 264.

In all these experiments, in which motion is produced by the escape of electricity from a point, the result is the same, whether it is the positive or the negative fluid that is used.

An amusing experiment is performed by cutting several images in paper, and placing them between two metallic plates, the upper one of which, A, figure 265, is suspended by a chain from the prime conductor of the machine, and the lower one,

by the escape of electricity from a point? How is the *electrical orrery* constructed? How is the experiment of the dancing images conducted?

Fig. 265.

B, connected with the earth. When the machine is turned the images are attracted by the upper plate, but as soon as they come in contact with it they are repelled, and fall; but striking again on the lower plate, their electricity is discharged, and they are again attracted to the upper plate, as before. They are thus made to dance in the most lively manner, skipping from side to side, as currents of air may happen to move them.

Suspend from a rod fixed in the prime conductor the piece of apparatus called the *electric bells*, which consists of three bells, A B C, figure 266, attached to a metallic rod; the first two, A and B, by metallic chains, and C by a cord of silk. Between the bells hang two clappers, by silk threads, and from the central bell, C, a chain extends to the table or floor. On turning the machine the bells A and B, being connected with the prime conductor by conducting substances, will become positively electrified, and will therefore attract the clappers, which, however, after contact with A and B, are immediately repelled by them, and attracted by the central bell, C. On coming in contact with this, they discharge their electricity, received from A and B, and are again attracted by them, as before; and thus a constant ringing is produced, as long as the machine is turned. At every motion of each clapper, it will be perceived, a portion of the fluid is transferred from the outer bells to the central one, and thence to the earth, the superabundant electricity of the prime conductor being thus gradually discharged.

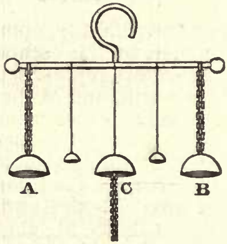

Fig. 266.

Fig. 267.

The electric spark may be made to pass through glass. For this purpose let an ounce vial, A, figure 267, partly filled with olive oil, be suspended from the prime conductor of the machine by a wire passing through the cork and bent so that the end may press against the glass on the inside, as shown in the figure. When the machine is turned, the point of the wire becomes highly electrified; and by presenting near it a metallic ball, or even the knuckle, a discharge will take place through the side of the vial, a

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What causes the bells to ring in the piece of apparatus illustrated in figure 266? How may the electric fluid be made to pass through glass?

very small perforation being made just at the point of the wire. By turning the vial a little, and making a line of perforations quite around it by successive discharges, it may at length be broken in two.

554. The electric fluid or fluids reside entirely upon the surface of bodies, as a hollow sphere of gold is capable of containing just as much electricity as if it were solid. Indeed, it seems to be retained merely by the pressure of the atmosphere, since, if an insulated body be excited and placed under the receiver of the air-pump, it loses its electricity almost instantly when the air is exhausted.

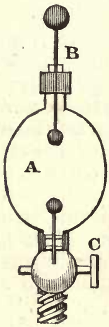

Fig. 268.

555. The electric spark will pass much farther in rarefied air than under the full atmospheric pressure. Let A, figure 268, be a glass receiver, with a metallic cap cemented on at each extremity. Connected with the cap C is a stop-cock and screw, by which it may be attached to the air-pump; and also a wire, with a knob at the extremity, extending a distance into the receiver. Through the other cap, B, a wire passes, air-tight, with a knob at each extremity. By holding this in the hand, by the cap, C, near the prime conductor, it will be found the spark will pass farther when the air has been partly exhausted than it would before the exhaustion. It is, of course, understood that the wire, B, is made to slide in the cap, so that the balls within the receiver may be adjusted to different distances from each other, as may be necessary. If the experiment is conducted in a darkened room, when the air in the receiver is highly rarefied, and the ball B held in contact with the prime conductor, as the machine is turned, a beautiful stream of pale light, not unlike that of the aurora borealis, will be seen between the balls in the receiver. If a receiver several feet long is used, a faint nebulous light will be seen to play through its whole length.

556. When a body is charged with electricity it may be discharged in three different ways. 1. The fluid may be conveyed away by a conducting substance, as a wire, extending from the the excited body to the ground. This is called the *conductive discharge.* 2. The fluid may pass by a spark, as when the knuckle is held near an excited body, or when the spark is made to pass through the side of a glass vial (§ 553). 3. The fluid may be conveyed away from an excited body by a motion communicated to the particles of air in contact with the

Quest. 554. Do the fluids in excited bodies reside entirely upon the surface? 555. Will the spark pass farther in rarefied air than under the full atmospheric pressure? What is said of the appearance of the electrical light, as the fluid passes through air highly rarefied? 556. When a body is charged with electricity, in what three ways may it be discharged? Why

body. This always takes place to some extent when a body is excited, though it is scarcely perceived. It is called the *convective discharge.* It is by this discharge that the fluid collected in a body will, in all cases, in process of time, be conveyed away.

To understand why the particles of air in the vicinity of the excited body should be put in motion, it is necessary only to refer to what takes place when the suspended pith-ball is brought near it (§ 537). The particles of air are first attracted, and then repelled, each of them carrying with it a portion of the electricity of the excited body, until it is all discharged.

INDUCTION.

557. When an electrified body is brought near another which is unelectrified, the natural electricity of the latter is disturbed by the influence of that accumulated in the former; and the term *induction* is used to indicate the general phenomena that ensue.

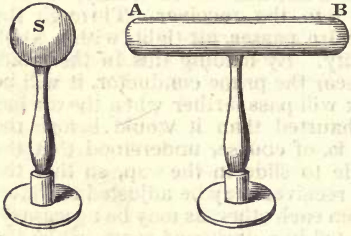

Fig. 269.

Let A B, figure 269, be an insulated cylinder of metal, in its natural state, and let S be a sphere, coated with metal and supported on an insulating pillar. Then let a spark of positive electricity be communicated to the sphere, S; it will instantly act upon the natural electricities of the cylinder, A B, which, upon examination, will be found to have positive electricity at the extremity B, and negative electricity at the other extremity, A, while near the centre, between them, it will be neutral. No electricity, it is supposed, has passed from the sphere to the cylinder, but the free electricity of the sphere has exerted an influence upon the natural electricity of the cylinder, decomposing it, and attracting the negative to the end A, and repelling the positive to the end B.

558. If the sphere, S, had been negatively electrified, the same effect would have been produced upon the electricity of the cylinder, A B, except that the end A would have become positive and the end B negative. Whether the sphere were electrified positively or negatively, the part of the cylinder farthest from it would have the same kind of electricity, and the part next to it the opposite kind. In either case, too, on the

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are the particles of air in the vicinity of an excited body put in motion? 557. What is the effect when an electrified body is brought near one that is unelectrified? When the excited sphere, S, figure 269, is brought near the insulated cylinder, A B, what effect is produced upon the natural electricity in A B? 558. If the sphere, S, had been negatively electrified, what would

removal of the excited body, the natural electricities of the cylinder combine, and it again becomes neutral in every part.

By some the sphere, S, is called the *inductive*, and the cylinder, A B, in this experiment, the *inductric* body.

559. If the finger be presented to either end of the cylinder, A B, while under the influence of the excited sphere, S, a spark will be received; and on the removal of the sphere, A B will not be neutral, as before, but there will be an excess of one or the other, according as the finger may have been presented to the positive or negative (§ 558) part of the cylinder.

If the inductive sphere had been placed near the centre of the cylinder, then both extremities would have the same electricity as the sphere, and the centre the opposite kind. In any case that part, or those parts, of the inductric (it being supposed to be insulated), will have the same electricity as the inductive body, while the part or parts near it will have the opposite kind.

560. A good method of showing the inductive influence of an electrified body upon another in its vicinity, in its natural state, is as follows:—Let A B, figure 270, be a metallic cylinder, insulated upon a glass pillar, bent over at top so as to be attached to the upper side, and let pieces of pith-ball be suspended from it by cotton threads at each extremity and at the centre. While the cylinder is in its natural state the balls will hang vertically, but on bringing near the excited sphere, S, the balls at each extremity will diverge with free electricity, while those in the centre will be unaffected. The balls at B diverge with the same kind of electricity as is contained in the sphere, S, but the balls at A with the opposite kind.

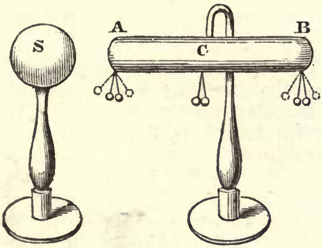

Fig. 270.

If the inductric is not insulated, and is of limited extent, the whole of it, while under the influence of the inductive, will take the opposite kind of electricity, that of the same kind naturally existing in it being driven into the earth.

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have been the result? If the excited body is removed, what will be the effect? 559. If, while the sphere, S, is near A B, the finger is presented to one of its ends, what will be the effect? If the sphere be now removed, will the cylinder be neutral? If the sphere is placed opposite the centre of the cylinder, what kind of electricity would the ends be found to have? 560. If the cylinder have several pairs of pith-balls suspended from it by cotton threads, as in figure 270, how will those suspended from different parts be affected when the excited sphere is brought near one end? If the inductric is not insulated, and is of limited extent, what will be the effect of the inductive upon it?

561. We have heretofore seen (§ 544) that similarly electrified bodies repel each other, while bodies dissimilarly electrified attract. This principle will, no doubt, serve to explain the phenomena of induction, as the separation of the electricities naturally existing in a body, in the manner we have seen, when brought near another excited body, seems to be only a natural and necessary result of it.

We may here see why light bodies are attracted when brought near an excited body; they are evidently first rendered electrical by the inductive influence of the excited body, and then attracted by virtue of their being in the opposite electrical state. Electrical attraction never takes place between two bodies unless they are in opposite states. So, when the attracted body has once come in contact with the excited body, it takes a portion of its electricity, and is then repelled as having the same kind of electricity.

562. In these experiments nothing but air has been supposed to intervene between the excited body called the inductive, and the inductric, or body acted upon; but the same effect, though in different degrees, will be produced through glass, wax, sulphur, or other non-conducting substances; which, when thus used, are called *dielectrics*.

563. *The Electrophorus.*—The *electrophorus*, or *electricity bearer*, is an instrument for readily obtaining small quantities of electricity. It consists of a circular cake of resin, contained in a shallow tin dish, C D, figure 271, and a circular metallic disc, A B, a little smaller than the cake of resin, furnished with an insulating handle of glass. To charge it, the metallic disc is removed, and the surface of the resin rubbed with a piece of dry warm flannel, by which it becomes negatively electrified, and is capable of retaining its electricity for a great length of time. If the metallic disc, A B, be now placed upon it, by means of its insulating handle, its natural electricity will be decomposed by the inductive influence of the resin, its positive electricity being attracted to the lower surface, while the negative is expelled to the upper surface. If the plate of metal is removed by its insulating handle, the electricities at once unite as before, and no indications of electricity appear; but if, while it rests upon the cake of resin, the finger is touched to the upper surface, a

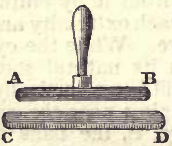

Fig. 271.

Quest. 561. Why are light bodies attracted when brought near an excited body? Why is the pith-ball of the electrometer repelled after contact with an electrified body? 562. Will the inductive influence of an excited body be exerted through other non-conducting substances besides air? 563. What is the *electrophorus?* What does it consist of? How is it charged? When the cake of resin is charged by friction, what is the effect upon the natural electricity of the metallic plate when placed upon it? If the finger be now

spark of negative electricity is received; and, after being removed from the resin by its insulating handle, it will be electrified positively; that is, an excess of positive electricity will be contained in it, and a smart spark of positive electricity may be received from it.

As no electricity is taken from the cake of resin in this experiment, if the disc is again applied to it, the same results will follow as before for almost any number of times. A cake of resin, prepared in this manner, has often been known to retain its charge for weeks, and even months, though not without some loss of intensity. The electrophorus may therefore often be used as a substitute for the electrical machine, when only small quantities of electricity are required.

The resin cake may easily be prepared by melting together two parts of shel-lac and one part of Venice turpentine, and pouring it, while warm, into the shallow metallic dish prepared for it. Care should be taken that the surface be made perfectly smooth and even. When the surface of the resin is negatively excited, the metal composing the dish will always be positive.

564. An amusing and not uninstructive experiment may be performed with the cake of resin thus prepared, as follows:—Let it be entirely free from electricity, and then touch it in several places with some positively electrified body, and afterwards in several other places with another body negatively excited. Then grind together some fine red lead and sulphur, and introduce the mixture into a common hand-bellows, and blow it against the face of the cake standing on its edge. The two substances will entirely separate from each other, one adhering to those points which were touched by the positively electrified body, while the other will attach itself only to those places touched by the negative body. The reason, no doubt, is, that the red lead and the sulphur, by friction, become excited, one positively and the other negatively, so that, when blown against the cake of resin, each is attracted to those parts of its surface which is in the state the opposite of its own.

565. *Electrometers.*—There are two kinds of electrometers—those which are used simply for determining the presence of free electricity, and those which are used for determining both its presence and its intensity. Of the first kind is the suspended pith-ball, figures 254 and 255, of which no further description is needed.

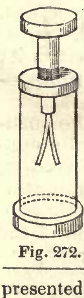

Fig. 272.

The gold-leaf electrometer is a more sensitive instrument, and may be used to indicate the presence of smaller quantities of electricity. It consists of a cylindrical glass vessel, figure 272, with a metallic bottom and a metallic cap at top, from which two narrow slips of gold-leaf are suspended in the inside. When an electrified body is brought over the instru-

presented to the upper surface of the plate, what will be the effect? If the plate is then removed by its insulating handle, what will be its electrical state? May this process be often repeated? Will the resin long retain its charge? 565. What two kinds of electrometers are there? How is the gold-leaf electrometer constructed? How does it show the presence of

ment, the gold leaves are made to diverge by the electricity induced in them by the excited body. The instrument is exceedingly delicate.

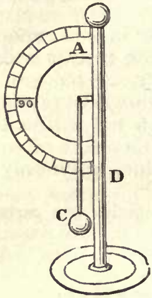

Fig. 273.

The quadrant electrometer, figure 273, consists of a graduated semicircle of ivory, A, attached to an upright support of wood, D, and a light index, terminating in a pith-ball, C, and moving on a pin fixed in the centre of the graduated semicircle. When this instrument is placed on any electrified body, as the prime conductor of the electrical machine, the index is made to rise by repulsion; and the degree at which it stands is supposed to indicate, with some accuracy, the comparative intensity of the charge.

566. *The Leyden Jar.*—This piece of apparatus has received its name from the city of Leyden, in Holland, where it was invented. It is simply a glass jar or phial, figure 274, of convenient size, coated internally and externally with tin-foil, except a space, some three inches wide, around the mouth. For conveniently inserting the inside coating, a vial with a wide mouth is usually selected. Through a varnished wooden cover, A, which closes the mouth, a brass wire passes, having a ball at top, and at its lower end a chain, B, which extends to the internal coating.

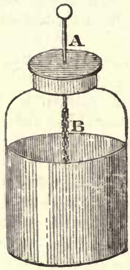

Fig. 274.

To charge the jar the knob at top is to be held near the prime conductor of the machine, when a succession of sparks will be seen to pass between it and the prime conductor. The positive electricity then collects rapidly on the inside coating, and by its inductive influence on the outside coating, causes an equal quantity of the negative to collect there, at the same time expelling the positive naturally contained in it; so that, when the jar is charged, the two surfaces are in opposite electrical states.

567. When charging the jar the outside must not be insulated, as in that case the positive fluid which is naturally contained in it could not escape, and then the outside coating would not receive the positive fluid from the prime conductor.

A series of jars may be charged at the same time by connecting the external coating of the first with the knob of the

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electricity? How is the quadrant electrometer constructed? 566. From what does the Leyden jar receive its name? How is it constructed? How is it charged? As the internal surface becomes charged with positive electricity, what effect is produced on the external coating? 567. Can the jar be charged while the external coating is insulated? What is the reason? How may a series of jars be charged at the same time?

second, the external coating of the second with the knob of the third, and so on, all except the last being supposed to be insulated. Let A B C D, figure 275, be four Leyden jars, placed on insulating stools, and connected together as shown in the figure, the knob of the first, A, being connected with the prime conductor. As the positive fluid accumulates in A, it acts by induction on the outside coating, separating its natural electricities, and causing the negative to accumulate in it, while the positive passes along the chain to the inside of B. In B the same effects are then produced as in A, and so on to the end of the series, the outside of the last being connected with the floor of the room.

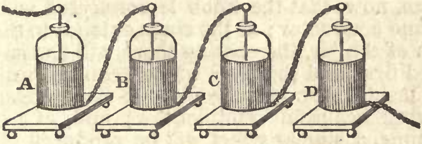

Fig. 275.

568. The jar, as usually charged, contains, as we have seen, positive electricity in the internal coating and negative in the external coating: but it may be charged negatively; that is, so that the electricities of the coatings may be the reverse of the above. This is done by insulating the outside of the jar, and connecting it with the prime conductor, at the same time extending a wire from the knob to the table on which the apparatus is placed.

569. The Leyden jar is discharged by forming a connection between the internal and external coatings, when the two electricities combine with a loud report. By making the communication with the hands the fluids pass through the system, producing the *electric shock.*

To prevent the passage of the charge through the person the *discharging-rod* is generally used. This instrument, figure 276, is made of two stout wires, connected by a joint, like a pair of compasses, and terminated by knobs, and fixed to an insulating glass handle. By means of the joint it may be opened to different distances, as may be required.

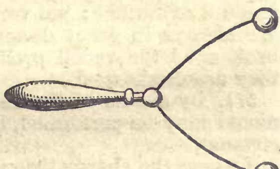
Fig. 276.

Some interesting experiments may be performed by means of jars having the coating interrupted. *Diamond jars*, figure

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Quest. 568. How may the jar be charged negatively? 569. How is the jar discharged? How is the *electric shock* produced? What is the use of the *discharging-rod?*

277, are formed by pasting small pieces of tin-foil at short distances from each other, both outside and inside, except the bottom, which is entirely covered. Suppose, now, that the knob is connected with the prime conductor; as the chain extends to the bottom of the jar, the coating there will become charged first, and the fluid will extend upward, on the inside, from piece to piece of the coating, producing beautiful scintillations; and, at the same time, a similar effect will be produced on the outside, as the pieces of coating become charged with negative electricity.

Fig. 277.

570. If the jar is provided with a continuous metallic coating inside, and the outside coated by covering it with solution of glue, and sprinkling on it some brass filings, when it is connected with the prime conductor, as the positive fluid is collecting in the internal coating, the accumulation of the negative on the outside will be shown by the darting of bright sparks over it, very much resembling flashes of lightning that are often seen in the clouds. Around both the top and the bottom there should be a strip of tin-foil.

Sometimes two or more Leyden jars are used together, by connecting all the interior coatings by means of wires extending from knob to knob, and all their exterior coatings by placing them in a box lined with tin-foil. It is then called an *electrical battery*, figure 278. At A is a hook, which connects with the external coatings of the jars. The effects of the battery are in all respects the same as would be produced by a single jar with an equal amount of surface; but very large jars are always in great danger of being broken by the recoil produced when they are discharged.

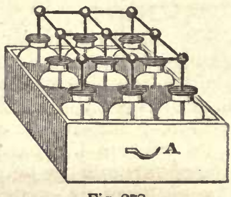

Fig. 278.

571. By means of the Leyden jar many interesting experiments may be performed, illustrating the nature of this subtle element.

To pass the charge through any body, it is necessary only to cause it to make a part of the circuit connecting the positive internal coating of the jar with the negative external coating. The piece of apparatus called the *universal discharger* answers well for this purpose; which consists of two stout brass wires,

Quest. 570. If a jar is coated internally with tin-foil and externally with metallic filings, what will be the appearance as it is charged? What is the *electrical battery?* 571. How may the charge of a jar be passed through a body? What is the design of the *universal discharger?* What is the effect

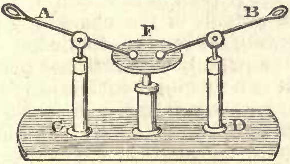

Fig. 279

A and B, figure 279, supported on glass pillars, C and D, by caps furnished with joints, so as to allow them to turn in any direction. They also slide in the caps, to allow the balls at their extremities to be placed at any desired distance from each other. At E is a table of wood, which may be elevated or depressed at pleasure, for the support of any substance to be submitted to experiment.

Let a dry card, or the cover of a book, be placed between the knobs of the discharger, and the charge of a large jar be made to pass through it. It will be found that a hole is pierced quite through it; and it will be burred outward on both sides, as if the force had burst outward from the inside of the card.

Put a piece of gold-leaf between two pieces of white paper, press them lightly together, and place it between the knobs of the discharger, so that they may be in contact with its opposite edges; after the discharge the paper will be found stained of a purple colour by the oxide of gold which has been formed. The same effect will be produced upon pieces of glass between which a piece of gold-leaf has been placed, and made to convey the electric discharge; but usually the glass will be more or less broken.

If the fluid be passed through a piece of loaf sugar, or of fluor spar, it will, for a moment, shine with a feeble phosphorescent light.

By passing the charge through a bunch of cotton or tow, over which some powdered rosin has been sprinkled, it will often be inflamed.

The smallest spark of electricity is capable of exploding a mixture of oxygen and hydrogen gases. To accomplish this a Leyden jar is not necessary, a mere spark from the prime conductor being sufficient. The spark, of course, must be made to pass through a portion of the mixture.

Gunpowder may be exploded by passing through it the charge of a Leyden jar, when confined in a small space, but not without some difficulty. The experiment succeeds best when a piece of linen or cotton thread, well soaked in water, makes a part of the circuit.

We have seen above (§ 569) the mode in which a person receives the electric shock, as it is called; in the same manner a number may receive it at the same instant, by grasping each

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of passing the charge through a piece of dry card or the cover of a book? How may a strip of gold-leaf be oxydized? What will be the effect of passing a charge through a piece of loaf sugar or fluor spar? What other experiments are described? How may gunpowder be fired?

other's hands and forming a line, the person at one end of the line pressing his hand against the outside of the charged jar, and the one at the other end presenting his knuckle to the knob.

572. It was long supposed that the passage of electricity over conductors is instantaneous, but it is now found such is not the fact. By some very beautiful experiments it has been shown that the fluid passes over copper wire, and probably other conducting bodies, at the rate of about 288,000 miles a second, which is considerably more rapid than light (§ 337).

573. *The Condenser.*—This is a piece of apparatus for collecting together or *condensing* in a small space, so as to render its action perceptible, very feeble electricities. It consists of two metallic discs, A and B, figure 280, placed face to face, and separated only by a coating of resinous varnish, with which they are covered. The upper plate, A, called the *collecting plate*, has attached to its centre a glass handle, C, by which it may be lifted from the *condensing plate*, B, and from its edge a wire projects, terminated by a metallic knob, D. By this it may be put in connection with another body, the electrical state of which it is proposed to examine. The condensing plate, B, is supported by a metallic stand, and, of course, is uninsulated.

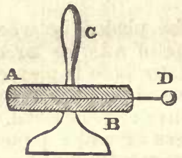

Fig. 280.

If we now connect any feebly electrified body with the knob, D, a portion of its electricity will be diffused over the whole plate A, and, by its inductive influence, the opposite kind will be collected in B (§ 557); this, in turn, will react upon A, and thus draw into it, or condense in it, a larger quantity of the fluid than it would otherwise have possessed. By separating A first from the feebly electrified body, and then raising it carefully by its glass handle from the plate B, the electricity it contains may be examined at leisure. Often a considerable quantity may thus be collected in the plate from a body so feebly electrified as to be scarcely capable of affecting the nicest electrometer.

If, while the plates are in the position indicated in the figure, the disc, A, should be examined by the electrometer, it would scarcely give any signs of electric excitement, since most of the fluid contained in it would be held there by the opposite electricity of the lower plate. This electricity thus concealed in A is called *dissimulated* or *latent* electricity, in opposition to free electricity, which alone is capable of acting on the electrometer.

574. *The Hydro-Electric Machine.*—It has recently been discovered that electricity is rapidly evolved by a jet of steam as it escapes from a common steam-boiler; and it has been determined that it is occasioned by the friction of the steam and particles of condensed water against the sides of the pipe. The hydro-electric machine, therefore, consists of a strong steam-boiler, which is to be insulated, having many small pipes, through all of which the steam may be allowed to escape at the same time. As the steam escapes the boiler becomes highly charged with electricity, in some cases throwing off sparks to the distance of two feet, or more.

Quest. 572. What is the velocity with which the electric fluid passes over copper wire? 573. What is the design of the condenser? What does it consist of? 574. What occasions the electricity developed by a jet of steam?

ATMOSPHERIC ELECTRICITY.

575. The atmosphere, especially when in a dry state, is, as we have before seen (§ 546), a non-conductor, consequently it is capable of retaining either of the electric fluids communicated to it; and different portions of it, or different strata, may be in different electrical states at the same time. This, we know by experiment, is often the case. Usually, in fair weather, the air near the surface is positive, and the intensity increases as we ascend, while the surface of the earth beneath is negative. In stormy weather, at all seasons of the year, the air near the surface is sometimes positive and sometimes negative; and not unfrequently sudden changes take place from one state to the other.

576. The usual method of determining the electrical state of the air, or that portion of it near the earth, is to erect a pointed metallic rod some 30 feet in length, and insulate it, connecting its lower extremity only with the electrometer, or such other electrical apparatus as it may be necessary to use. If the electric bells are connected with the rod, the presence of electricity of sufficient intensity will always be indicated by their ringing, but they will not be affected when the electricity is very feeble.

577. It has not yet been satisfactorily determined by what means the electricity of the atmosphere is developed. Various causes have been assigned, as the evaporation that is constantly taking place at the surface, and the condensation of vapours in the upper regions of the atmosphere; but recent investigations render it probable that it is occasioned by the friction of currents of air against each other, and against the earth, and also against particles of water and other substances which are always floating in it. Consequently, vivid lightnings usually attend the eruptions of volcanoes, especially in those cases in which immense columns of black smoke, composed of dust and ashes, are belched forth into the air. The lightning is also often attended by thunder.

578. The clouds, which are only masses of aqueous vapour partially condensed by the cold of the upper strata of the atmosphere, being tolerably good conductors, serve to collect the free electricity of the atmosphere, and, therefore, often become highly excited, and discharge their electricity from one to another, or to the earth, producing all the phenomena of thunder

Quest. 575. Is atmospheric air a non-conductor? May different strata of it be in opposite electrical states? In fair weather what is usually the state of the air near the surface? Does the intensity increase upward? What is the state of the surface of the earth beneath? In stormy weather what is the state of the air? 576. What is the usual mode of determining the electrical state of the atmosphere? 577. What probably occasions the electricity of the atmosphere? Are lightnings generally seen to attend volcanic eruptions, when immense volumes of dust and ashes are belched forth into the air? 578. What are clouds? May they become highly excited, and

and lightning. Franklin was the first to suggest this explanation of lightning and thunder, about a century ago, and soon afterwards proved the truth of his suggestion by actual experiment. This he did by sending up a large kite, held by a hemp string, which conducted the fluid freely downward, especially as soon as it was moistened a little by the falling rain. At the lower end a short piece of silk cord was used, in order to insulate it. With this apparatus he obtained sparks, charged the Leyden jar, and performed other electrical experiments, which, since his day, have often been repeated.

579. A thunder-cloud is to be considered the same as any other cloud, except that it is charged with electricity. Such clouds, in New England, usually make their appearance in the west or north-west, in the afternoon or evening, during the warm weather of summer, and gradually approach, all the time increasing in size and blackness, until at length they pass over our heads and disappear in the east or south. During the whole time frequent lightnings and thunder are taking place, with the fall of more or less rain, and sometimes hail. Not unfrequently damage is done and lives are lost by the lightning striking buildings, trees, and other elevated objects.

The discharge from such a cloud, which we call lightning, differs in nothing, it is believed, from the discharge of a spark from the prime conductor of an electrical machine, when the knuckle is presented to it, except in the quantity and intensity of the fluid.

580. Let us suppose a cloud positively electrified to be passing over a place, the earth and everything upon its surface beneath it for a distance will become negative by induction (§ 557), and whenever the cloud, in its passage, comes sufficiently near the earth, or any object upon its surface, a discharge will ensue between the earth and cloud. The distance at which the discharge will take place will depend upon circumstances, as the extent of the surface of the cloud electrified, its intensity, the conducting power of the air and vapours contained in it at the time, &c. Circumstances will also determine the direction the fluid will take, or the object upon the surface that will be struck. Other things being equal, the fluid always takes the course where the best conductors are situated, but sometimes it will take a course through a series of poorer conductors, provided the distance is less than through the good conductors.

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discharge their electricity to the earth? Who first suggested this explanation of thunder and lightning? How did he prove the truth of the suggestion? 579. From what part of the heavens do thunder-clouds usually appear to rise in New England? Does the discharge from a thunder-cloud differ essentially from the discharge of the spark from the prime conductor of an electrical machine? 580. When a cloud positively electrified is passing over a place, what will be the electrical state of the surface of the earth and other objects beneath it? When will a discharge take place? What will the distance depend upon at which this will take place? What will de

Lightning, it is well known, almost always strikes the highest objects at their highest point, though there are occasionally exceptions; and in its course it often rends in pieces the firmest substances, occasionally setting them on fire. Sometimes its course can be traced a distance in the earth, after leaving the object it first struck, but it is generally soon diffused abroad, and its mechanical effects cease. All these effects are just such as we might expect to be produced by an immense electrical machine, provided we were able to construct one of sufficient power.

581. When a spark is received from the prime conductor of the machine, or when the Leyden jar is discharged, a single report only is heard; whereas thunder, which is merely the report of the electric discharge from the clouds, is often a long-continued rolling sound. This, it is believed, is occasioned by numerous echoes from the masses of cloud scattered at various distances from the ear of the observer, which, of course, will arrive successively to the ear, and occasion an apparent repetition (§ 303) of the original report. It may be, indeed, as has been suggested, that the sound itself is not produced at a single point, but along the whole line constituting the pathway of the fluid; and the original report may then be considered as a succession of reports originating at different distances from the ear, and though produced all along the line at the same instant, yet necessarily arriving successively. Thus, let A, 1, 2, 3, B, figure 281, be the path of the fluid at an explosion or discharge, and let O be the place of the observer; if the sound is supposed to be produced all along this line, it is plain that the sound from the nearest point, as 1, would arrive at O first, then that from other points in succession, according to their distance. The effect would evidently be the same as we witness in the continued rolling sound of thunder. And the path of the fluid is not straight, but zigzag, backward and forward, as represented in figure 282, which we may suppose greatly to increase this peculiarity.

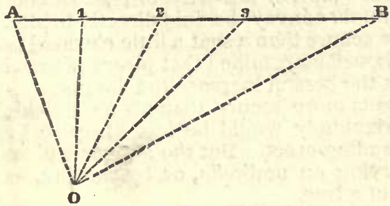

Fig. 281.

termine the direction the fluid will take? What parts of objects does lightning usually strike? 581. What is believed to occasion the continued rolling sound of thunder? May the sound be supposed to be produced at different points along the path of the fluid? How would this occasion it to appear protracted to the ear?

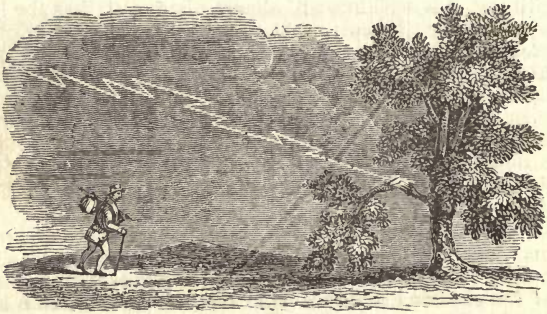

Fig. 282.

582. As lightning usually strikes the highest objects, and follows the course of the best conductors, it is not difficult to determine the position of the greatest safety. If the person is in a building, he should remove as far as possible from the chimney, the soot of which often serves as a very good conductor to the fluid, and from any large timbers the house contains, especially those leading downward from any part of the roof; he should also remove to a distance from any metallic conductor passing through the house, as a stove-pipe, or bell-wire, or pipe for conveying water, as all these might convey the fluid directly to him. Probably no place is more secure than a seat a little elevated in the centre of a room. It is well ascertained that pieces of metal of any kind carried about the person increase the danger.

In the open air no place is more secure than an open field; and a person lying horizontally would be less likely to be struck than if he were standing erect. But the danger will be greatly increased by carrying an umbrella, or by seeking, as is often done, the shelter of a tree.

583. The distance of an electrified cloud may be estimated by noticing the number of seconds that elapse after the lightning is seen before the thunder is heard. As sound moves about 1125 feet (§ 300), or nearly a fifth of a mile, in a second, while the passage of light for so small a distance may be considered instantaneous, it is evident the explosion must take place at the distance of about a mile for every five seconds of time that thus elapse.

Quest. 582. Where, within a building, is the position of greatest safety during a thunder-storm? Will pieces of metal worn about the person increase the danger? What position is considered most secure for a person in the open air? What is said of the propriety of seeking shelter under a tree? How may the distance of an electrified cloud be estimated? 583. How far will the cloud be for every five seconds that elapse after the lightning is seen before the thunder is heard?

584. *Lightning-rods*, or, as the French call them, *paratonnerres*, are metallic rods, attached to buildings and other objects, and extending a distance above them, to protect them from danger from electric discharges between the clouds and the earth. They are usually made of iron, and should always extend several feet above the highest point of the object to be protected, and terminate in a point; and should also connect at the bottom with the moist earth. The rod should not be less than half an inch in diameter, and it is of little consequence whether it be round or square. It should also be made of as few pieces as possible, and these should be brought firmly in contact, as by screwing one into the other. If a large building is to be protected, there will be an advantage in using several smaller rods instead of one large one; but they should all be connected together, and should have branches extending to all the more exposed parts of the building.

585. The benefit of electrical conductors to buildings and other objects liable to injury by being struck by lightning is twofold. In the first place, if a discharge actually takes place upon the building, the conductor, if properly constructed, will almost certainly convey the fluid harmless to the ground. Occurrences like this have been frequent. And, when buildings unprovided with proper electrical conductors, but having metallic wires or bars extending through them, have been struck, it has generally been found that the fluid has followed the metal as far as it extended on its course, and has damaged the building only before reaching the metal, or after leaving it. It therefore not unfrequently happens, that buildings having metallic tubes for conveying the water from the eaves downward, when struck by lightning, are injured only in the roof, the fluid from this point following the tube to the ground.

In the second place, electrical conductors attached to buildings, when properly connected with the moist earth, seem to convey the electricity of the clouds silently to the earth, and thus often, no doubt, prevent a disruptive discharge, which might otherwise have occurred, and done great injury. The effect of presenting a pointed conductor in the vicinity of an electrified body we have heretofore (§ 548) seen. If a person standing near the prime conductor of an electrical machine presents in its vicinity the point of his pen-knife, as the ma-

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Quest. 584. What is the design of the *lightning-rod*? How is the lightning-rod made? How should it terminate at the top? With what should it connect at the bottom? Will there be an advantage in having several rods connected together for a large building? 585. In case a discharge actually takes place upon a building, how does the conductor protect it? Why are buildings provided with water-conductors, extending from the eaves downward, often injured only in the roof? Do lightning-conductors, in all probability, often convey the electricity of the clouds silently to the earth, and thus prevent a disruptive discharge? What will be the effect if a person standing near an electrical machine, as it is turned, presents the point

chine is turned, scarcely any electricity will be collected, as it will nearly all be conveyed away by the metallic point. And the same effect will be produced upon the electricity of the clouds by pointed conductors presented towards them.

586. When the atmosphere is highly charged with electricity the points of bodies projecting into the air often appear luminous in the dark. This was probably the cause of the fire seen upon the points of the spears of a division of the Roman army, in ancient times, mentioned in history; and it is here, too, we are to look for an explanation of meteors often seen, during storms, upon the extremities of the masts and spars of shipping, called, by sailors, Castor and Pollux, or fire of St. Elmo. The points of electrical conductors attached to buildings have been known to present the same appearance when highly electrified clouds have been passing over them; and there can be no doubt the cause in each case is the same.

587. That conductors attached to buildings do really protect them from injury from lightning has been abundantly proved by actual experiment a thousand times. It is a remarkable fact, as Arago suggests, that the temple at Jerusalem, which stood from the time of Solomon until the year 70 of the Christian era, a period of about 1000 years, though situated on an eminence in a region where thunder-storms are common, we have reason to believe from the silence of history, was never once struck by lightning. The reason plainly was, that it was protected by its thick gilding, it having been entirely overlaid with gold; and each end of the roof was adorned with a row of long lances of iron, which were pointed at top, and gilt. Metallic pipes, for water-conductors, also, extended from the roof to cisterns constructed under the porch. The building was, therefore, admirably protected from danger from lightning, in close accordance with the most approved principles of modern science.

588. *Water-Spouts and Land-Spouts.*—Water-spouts, which are often seen at sea, apparently consist of dense columns of aqueous vapour, extending from the clouds to the surface of the ocean. They are usually observed to form as follows:—A dense black cloud, floating in the air, is seen to have forming on its under side an inverted cone, which rapidly increases, extending itself downward; and the surface of the water beneath, which before had been tranquil, begins to be agitated, and apparently to boil; and soon an immense column rises, with a rapid whirling motion, until it joins the inverted cone

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of his pen-knife in the vicinity of the prime conductor? 586. What is said of the appearance in the dark of the points of objects projecting in the air when highly electrified? Are meteors often seen by sailors, during storms, upon the ends of the masts and spars of ships? 587. What reason is given why the temple of Solomon, at Jerusalem, was, as we believe, never struck by lightning? 588. What do *water-spouts* apparently consist of? What is

connected with the cloud, thus forming a whirling pillar of dense vapour, reaching from the cloud to the surface of the sea. Not unfrequently, two or more of these are seen in the immediate vicinity of each other, as represented in figure 283.

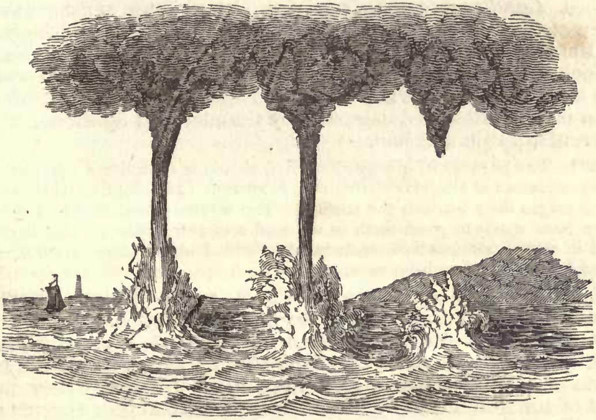

Fig. 283.

The cause of the formation of water-spouts, no doubt, is the highly electrified state, either positive or negative, of the clouds, inducing the opposite state in a portion of the sea below them. By the attraction of the opposite electricities they are then drawn together, the water of the sea rising in the form of spray or vapour, while a portion of the cloud descends, until the two unite and a communication is established between them. During the continuance of the phenomena, therefore, which sometimes is only a few minutes, and at others several hours, often no lightning or thunder is observed, as the opposite electricities are silently discharged through the continuous conducting medium which is in this extraordinary manner established. At other times they are attended by violent thunder and lightning, or merely by flashes of light without a report. The whirling motion is probably produced by the rushing of the surrounding air and vapours towards the centre of the influence, where the column is formed.

589. Ships coming in contact with water-spouts have often been inundated with torrents of water, and destroyed; but, in

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the mode in which they have been observed to form? What is the cause of their formation? Are they often attended by lightning and thunder? How is their whirling motion accounted for? 589. Are ships in danger of being destroyed in coming in contact with them?

some instances they have escaped. When they are seen near a ship of war, the sailors often attempt to fire a cannon-shot into them, by which, it is said, they may often be broken and destroyed, and the danger from them avoided.

590. *Land-spouts* appear to be produced in the same manner as water-spouts, except that they occur over the land instead of the sea. They are usually attended by a violent whirlwind, which levels everything in its course, destroys buildings, tears up trees, often removing them, and even other heavy bodies, to a considerable distance, and by thunder and lightning, with torrents of rain and hail.

591. The passage of highly electrified clouds is sometimes attended by the production of singular phenomena in springs and fountains which have their origin deep beneath the surface. The waters of well-known springs have been made to gush forth in unusual and extraordinary abundance; and in some instances fissures have been formed and streams issued where none had ever before been seen.

592. *The Aurora Borealis.*—This name, which signifies *Northern Morning*, is applied to luminous appearances which are, in clear weather, often seen at the north, soon after sunset, or later in the night. Sometimes they are presented in the form of a diffused white cloud, but more frequently they consist of luminous rays of various colours, issuing in various directions, but always converging to the same point. These rays are not permanent, but constantly change their position in every possible manner, sometimes presenting an appearance like the graceful folds of a riband or flag agitated by the wind, as represented in figure 284, and then dividing into several

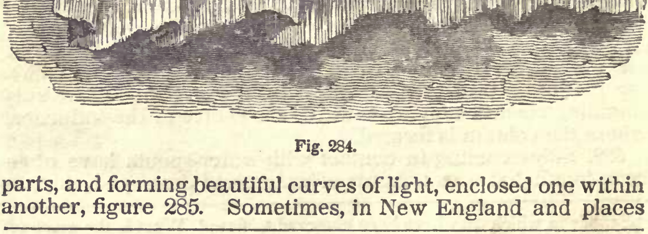

Fig. 284.

parts, and forming beautiful curves of light, enclosed one within another, figure 285. Sometimes, in New England and places

Quest. 590. What are *land-spouts?* With what are they usually attended? 592. What is the *Aurora Borealis?* What do they sometimes consist of? Do they frequently change their appearance?

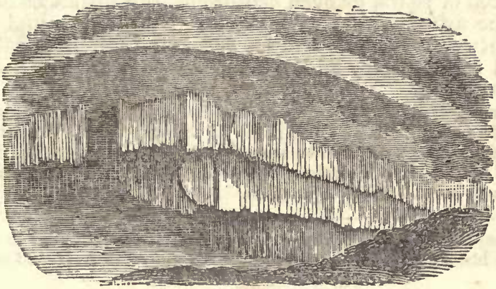

Fig. 285.

farther north, the whole heavens are lit up with them, which, for hours, or even during the entire night, continue to flash in every direction.

593. The mode in which this phenomenon is produced has not yet been fully established, but enough is known to prove conclusively its electrical origin. The streams of auroral light in every part of the heavens always tend towards the same point which is indicated by the direction of the south pole of the dipping-needle (§ 523); here they are often seen to unite, forming a beautiful arch or corona. It is well known, also, that during the occurrence of the aurora the magnetic needle is usually more or less affected, sometimes oscillating through several degrees. From the established connection between electricity and magnetism, (for the discussion of which see the author's work on Chemistry,) this is just what should be expected, considering this phenomenon to be produced by electricity by some means put in motion in the upper regions of the atmosphere.

594. A popular notion has very extensively prevailed, that the aurora borealis was entirely unknown to the ancients, and has been seen only in modern times; and some writers of no little merit have given countenance to the error. This has, no doubt, been occasioned by the fact that its occurrence with sufficient brilliancy to attract attention has been at very irregular intervals, it sometimes disappearing entirely

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Quest. 593. Has it been fully proved how they are produced? Is it certain they are of electrical origin? Towards what point in the heavens do the streamers of light always tend? What is often formed in this point? What is frequently the effect of the aurora upon the magnetic needle? Should this be expected from the known connection between electricity and magnetism, considering the aurora as the effect of electricity in the upper regions of the atmosphere? 594. What is said of the popular notion that has prevailed that the aurora borealis has been seen only in modern times?

for scores of years, or even centuries. But instances of its occurrence are recorded by Aristotle, Cicero, Pliny, and others; and, between the years A. D. 583 and 1751, it is said, it is alluded to in history as having been seen no less than 1441 different times.

Thermo-electricity, or electricity developed by change of temperature in certain cases, and also that branch of the science of electricity called galvanism, with its important connections with magnetism, are discussed in detail in the author's edition of Turner's Chemistry, to which reference has already several times been made.

Were they seen by the ancients? How many times is it said to be mentioned in history as having occurred between the years A. D. 583 and 1751?

THE END.